GEOLOGY OF THE GRENVILLE PROVINCE IN THE LAC JOSEPH AND OSSOKMANUAN LAKE AREAS (23A/NW and 23H/SW), WESTERN LABRADOR

Donald T. James

Report 94-2

St. John's, Newfoundland
1994

GOVERNMENT OF
NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Geological Survey Branch

COVER

Typical topography and vegetation in the northern part of the Lac Joseph terrane, western Labrador. In this area the hills are typically underlain by rocks of the ca. 1.64 Ga Ossok Mountain intrusive suite, and the valleys by high-grade paragneiss.

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ABSTRACT

The Grenville Province in the Ossokmanuan Lake and Lac Joseph areas, western Labrador, is constructed of two lithotectonic terranes defined as the Molson Lake and Lac Joseph terranes. These terranes, consisting principally of Labradorian-age crust (ca. 1720 to 1600 Ma), were assembled to form a bipartite structural stack in the Grenvillian Orogeny (ca. 1000 to 980 Ma), although they have significantly disparate Grenvillian characteristics.

The Lac Joseph terrane forms the upper structural deck and consists of amphibolite- to granulite-facies paragneiss, mafic intrusive rocks, and variably deformed granitoid rocks of several ages. Field relations and isotopic studies demonstrate that high-grade metamorphism and attendant deformation is Labradorian (ca. 1660 to 1600 Ma). Occurrences of Labradorian kyanite in the northern part of the terrane and sillimanite in the central and southern parts of the terrane suggest the terrane is an oblique depth section through Labradorian crust. The concentration of Labradorian-age mafic intrusive rocks in the northern part of the terrane implies that these were emplaced preferentially at intermediate crustal depths. Chemistry of the mafic intrusive rocks suggests that they may be genetically related to temporally equivalent granitoid rocks in the Trans-Labrador batholith. The Lac Joseph terrane contains only local evidence of Grenvillian thermal overprinting.

The Molson Lake terrane consists mainly of ca. 1650 Ma granitoid rocks correlated with the Trans-Labrador batholith and a lesser amount of ca. 1450 Ma Shabogamo Gabbro. In sharp contrast with the Lac Joseph terrane, rocks contain amphibolite-facies assemblages and penetrative structures that are Grenvillian in age.

A regionally persistent zone of ductile shearing separates the terranes and involves rocks in both. Deformation in the zone was attendant with Grenvillian amphibolite-facies metamorphism. An ensemble of kinematic indicators demonstrates that the Lac Joseph terrane moved to the northwest over the Molson Lake terrane. Minimum displacement is constrained at 120 km. Superposed, northwest- and east-northeast-trending Grenvillian folds deformed the Lac Joseph terrane after its emplacement, producing its lobate shape.

Grenvillian assembly of these two terranes could be accomplished by a major, late syn-metamorphic hinterland-stepping thrust that emplaced the relative shallow crustal-level rocks in the Lac Joseph terrane onto the deeper level and previously exhumed Molson Lake terrane. This resulted in addition of the Lac Joseph terrane to near the orogenic front, and balances the mass lost to rapid erosion of the deeply exhumed Molson Lake terrane in an entirely contractional Grenvillian Orogeny. This model also implies that thrusting, first migrated toward the autochthon with emplacement of the Molson Lake terrane and resultant formation of a fold-and-thrust belt (Gagnon terrane), and later migrated away (i.e., stepped back) from the autochthon, resulting in emplacement of the Lac Joseph terrane. Alternatively, the two terranes could be separated by a ductile extensional fault. Extension in the northeastern Grenville Province and northwestward emplacement of the Lac Joseph terrane may have been related to unroofing of a Grenvillian orogenic core zone, subsequent to regional contraction and culmination of Grenvillian crustal thickening at ca. 990 Ma along the northwestern margin of the orogen.

INTRODUCTION

LOCATION AND ACCESS

The study area is located in western Labrador, approximately 70 km east of Labrador City. The area mapped includes the southwest corner of the Ossokmanuan Lake map area (NTS 23H/SW), and the northwest corner of the Lac Joseph map area (NTS 23A/NW) (Figure 1 and Maps 93-53 and 93-54), an area of approximately 7500^2 km.

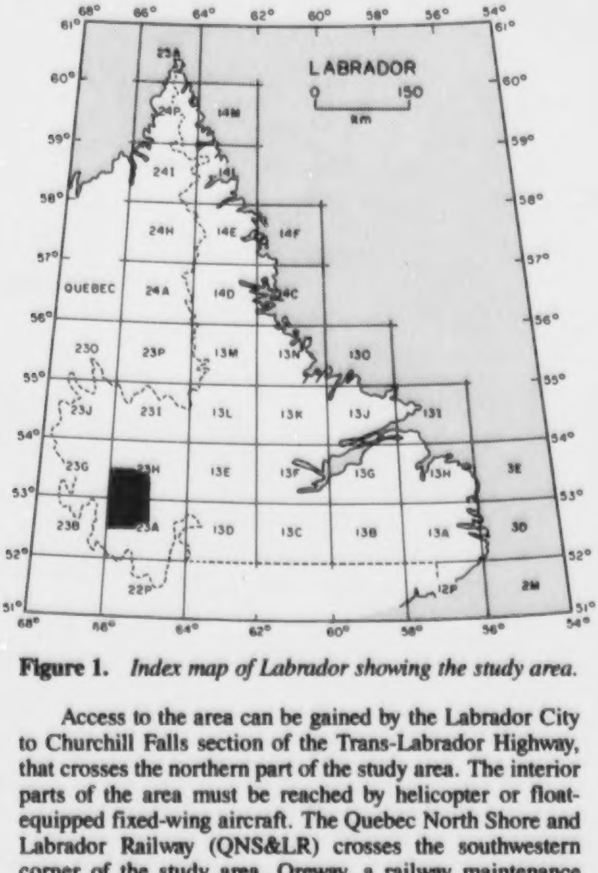


Figure 1. *Index map of Labrador showing the study area.*

Access to the area can be gained by the Labrador City to Churchill Falls section of the Trans-Labrador Highway, that crosses the northern part of the study area. The interior parts of the area must be reached by helicopter or float-equipped fixed-wing aircraft. The Quebec North Shore and Labrador Railway (QNS&LR) crosses the southwestern corner of the study area. Oreway, a railway maintenance station located on the QNS&LR line within the study area, is infrequently occupied.

The area was mapped by three, two-person traverse teams in one,three-month field season in 1990. Mapping was mainly helicopter-supported and carried out from a base camp on the Trans-Labrador Highway. A minor portion of the field work was accomplished using ground traverses based from the Trans-Labrador Highway, and from boat-supported camps on Lac Joseph and Ossokmanuan Lake.

OBJECTIVES AND PREVIOUS WORK

This project constitutes part of a regional mapping program, conducted by the Labrador Mapping Section of the Newfoundland Geological Survey Branch, involving investigation of the geology of the northeastern Grenville Province. Studies in this part of the Grenville Province, synthesized by Rivers *et al.* (1989), have shown that the region has been variably affected by two orogenic events, namely the Labradorian Orogeny and the Grenvillian Orogeny. The objectives of the 1990 mapping program were not only to map the distribution and disposition of rock units, and to describe the structural and metamorphic character of the area, but also to attempt to decipher the effects of these two orogenic events by focusing on structural and metamorphic relations, and the nature of regionally persistent shear zones that subdivide the area into a number of lithotectonic terranes. The results of this study helps to gain a better understanding of the geology and tectonothermal history of Labradorian-age crust, and the timing and effects of later, Grenville-age events.

The field objectives were met by systematically mapping the area at a scale of 1:100 000. This has resulted in an upgrading of the previous 1:250 000-scale maps of the area by Wynne-Edwards (1961) and Stevenson (1967). Selected parts of the area have also been mapped by Connelly (1988) as part of a thematic study directed toward some of the major structural features of the region. Preliminary results of the 1990 field season are reported in James *et al.* (1990, 1991) and James (1991). The study area is adjacent to areas mapped by Nunn and Christopher (1983), Nunn *et al.* (1984), Connelly and Scowen (1987), and Rivers (1985b,c) (Figure 2).

REGIONAL SETTING AND GENERAL GEOLOGY

Investigations in southern Labrador and adjacent parts of eastern Quebec have shown that the Grenville Province may be subdivided into a number of lithotectonic terranes (Figure 3) that are defined on the basis of contrasting rock types, and structural and metamorphic character (see Rivers, 1983; Gower and Owen, 1984; Rivers and Nunn, 1985; Rivers and Chown, 1986; Wardle *et al.*, 1986; Rivers *et al.*, 1989, 1991). The terranes are commonly separated by major, regionally persistent high-strain zones.

The study area (Figure 4) contains parts of the Molson Lake terrane (Connelly *et al.*, 1989) and the Lac Joseph terrane (Rivers and Chown, 1986). These two terranes are variably affected by the ca. 1720 to 1600 Ma Labradorian Orogeny (Nunn *et al.*, 1984; Nunn *et al.*, 1985; Thomas *et al.*, 1985; Thomas *et al.*, 1986) and the ca. 1000 Ma Grenvillian Orogeny, and have been proposed to be parautochthonous and allochthonous with respect to autochthonous pre-Middle Proterozoic North America (Laurentia) consisting of the Superior, Churchill and Makkovik provinces (Rivers and Chown, 1986; Rivers *et al.*, 1989). Both terranes consist mainly of Labradorian-age crust, although the Molson Lake terrane also contains mafic intrusive rocks belonging to the Shabogamo Gabbro (Frarey

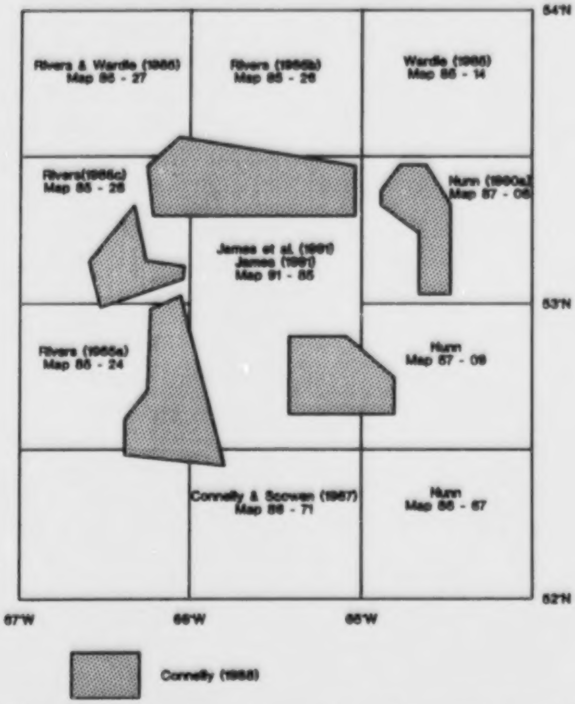
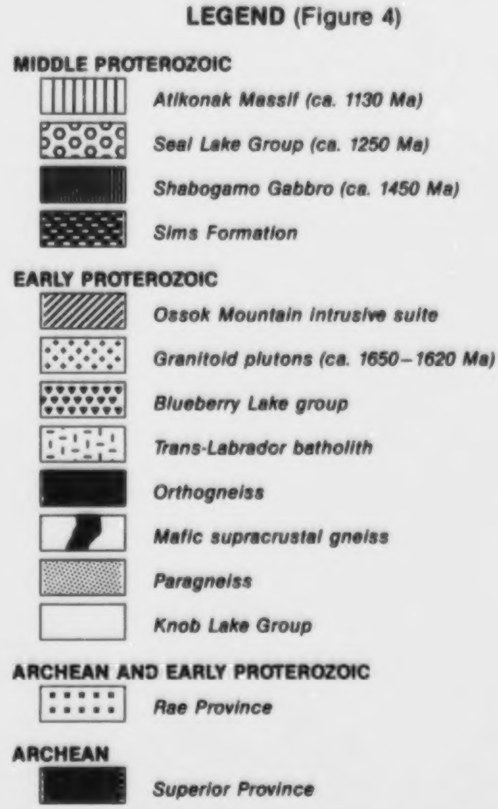


Figure 2. *Schematic index map of southwestern Labrador showing locations of previous mapping studies in the Grenville Province. Map references are Geological Survey Branch publications.*



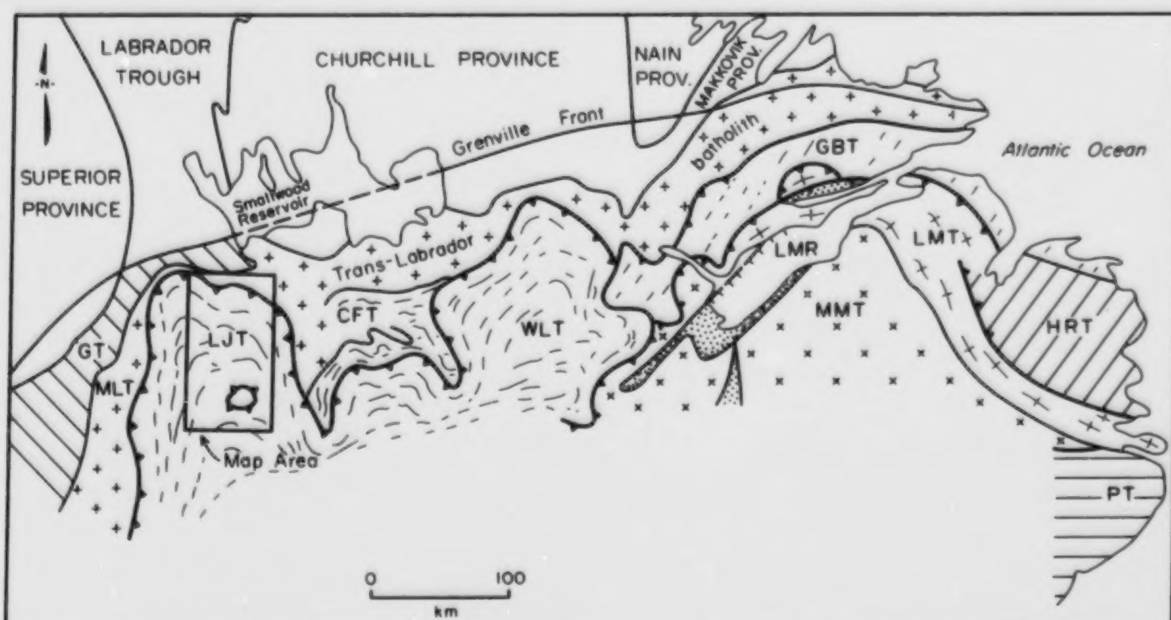


Figure 3. *Principal tectonic subdivisions of the northeastern Grenville Province, Labrador (modified after Wardle* et al., *1990). GT–Gagnon terrane, MLT–Molson Lake terrane, LJT–Lac Joseph terrane, CFT–Churchill Falls terrane, WLT–Wilson Lake terrane, LMR–Lake Melville rift system, MMT–Mealy Mountains terrane, GBT–Groswater Bay terrane, LMT–Lake Melville terrane, HRT–Hawke River terrane, PT–Pinware terrane.*

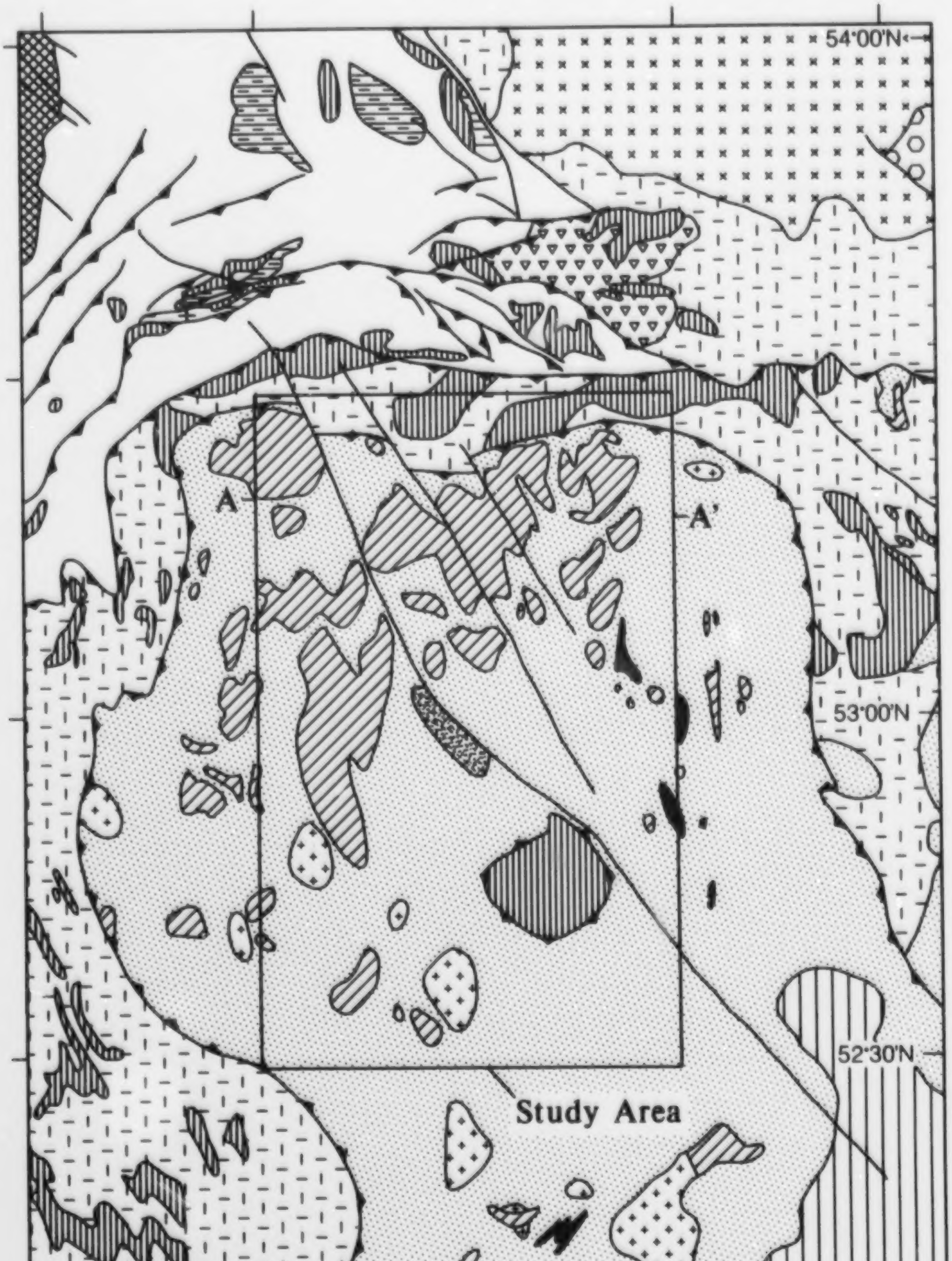


Figure 4. *Generalized geological map of the Grenville Province, southwestern Labrador.*

Table 1. Table of lithological units

Unit	Lithology	Description
Shabogamo Gabbro	olivine gabbro, gabbronorite, rare troctolite	variably metamorphosed and deformed gabbro and coronitic gabbro
charnockite–mangerite	charnockite, mangerite	isotropic, opx-bearing granite, and granodiorite
granite	granite, quartz monzonite	variably metamorphosed and deformed granitic rocks
Ossok Mountain intrusive suite	gabbronorite, norite, gabbro	metamorphosed mafic intrusive rocks
granitoid gneiss	granitoid gneiss	granodiorite to tonalite orthogneiss and migmatite
Trans-Labrador batholith	monzogranite, quartz monzonite, granite gneiss	variably metamorphosed and deformed granitic rocks
mafic supracrustal gneiss	mafic gneiss and migmatite	two-pyroxene and hornblende gneiss; minor paragneiss
paragneiss	paragneiss	migmatitic metasedimentary gneiss containing two phases of K-feldspar-bearing leucosome

and Duffell, 1964; Fahrig, 1967; Gower *et al.*, 1991a) whose igneous age has been determined using U–Pb zircon methods at 1459^{+23}_{-22} Ma by Connelly and Heaman (1993). In a recent subdivision of the Grenville Province, Rivers *et al.* (1989) have included the Molson Lake and the Lac Joseph terranes with their parautochthonous and allochthonous polycyclic belts, respectively.

The Lac Joseph terrane is composed of high-grade supracrustal gneisses, metamorphosed and variably deformed Labradorian-age mafic intrusive rocks, defined as the Ossok Mountain intrusive suite (James *et al.*, 1991), and metaigneous rocks including orthopyroxene-bearing megacrystic granite, granitoid migmatite, and charnockite–mangerite (Table 1). The rocks in the Lac Joseph terrane are intruded by unmetamorphosed but locally foliated Grenville-age pegmatites, and unmetamorphosed and undeformed mafic dykes of uncertain age.

The Molson Lake terrane, which structurally underlies the Lac Joseph terrane, is a metaigneous domain composed of variably metamorphosed and deformed rocks derived from the ca. 1650 Ma Trans-Labrador batholith (Wardle *et al.*, 1986) and Shabogamo Gabbro. Mapping and magnetic anomaly patterns suggest that the Molson Lake terrane can be traced around the northern margin of the Lac Joseph terrane into the Churchill Falls terrane (Connelly and Nunn, 1988). The Churchill Falls terrane differs from the Molson Lake terrane in that it contains a significant proportion of supracrustal rocks, thought to be equivalent with the supracrustal rocks in the Lac Joseph terrane (see Rivers and Nunn, 1985; Connelly and Nunn, 1988; James *et al.*, 1991).

Petrographic and U–Pb geochronological studies (Table 2) have shown that the extensive high-grade metamorphism in the Lac Joseph terrane is Labradorian in age, and that Grenville effects are restricted to areas of medium-grade retrogression that are primarily near the boundary with the Churchill Falls or Molson Lake terranes (Connelly *et al.*, 1990). In sharp contrast, Grenvillian metamorphism is significantly more pervasive in the Churchill Falls and Molson Lake terranes, reaching medium- to high-grade and high-pressure conditions (e.g., Rivers and Nunn, 1985; Connelly and Nunn, 1988; Connelly *et al.*, 1989; Indares, 1991, 1993).

The Lac Joseph terrane is separated from the Churchill Falls and Molson Lake terranes by a major, regionally persistent, ductile high-strain zone named the Lac Joseph terrane–Molson Lake terrane boundary zone (JMBZ). The high strain persists, although it is heterogeneously distributed, for several kilometres on both sides of the terrane boundary. An ensemble of kinematic indicators from the JMBZ confirms that the Lac Joseph terrane, the structurally higher nappe, was transported to the northwest over the Churchill Falls and Molson Lake terranes. In the Lac Joseph terrane, amphibolite-facies minerals have grown along high-strain structures of presumed Grenvillian age, resulting in a retrogression of pre-existing Labradorian assemblages. Similarly, amphibolite-facies assemblages have also grown along Grenvillian high-strain structures in Molson Lake terrane rocks.

Table 2. Summary of regional geochronological data for the Lac Joseph and Molson Lake terranes

Age in Ma	Systematics	Lithology	Interpretation	Reference
966 ± 30	U–Pb b,z	SH, MLT	Grenvillian metamorphism, Lac Joseph window	1
989 ± 12	U–Pb z D/LI	TLb, MLT	Reset zircon in shear zone from LJT-MLT boundary	2
994	U–Pb r C	SH, MLT	Grenvillian metamorphism	2
995 ± 8	U–Pb t D/LI	TLb, MLT	Grenvillian metamorphism	2
999^{+5}_{-3}	U–Pb m C	peg, LJT	Igneous age of pegmatite	2
1001 ± 7	U–Pb t D/LI	grn gns, LJT	Grenvillian metamorphism in Lac Joseph Terrane	1
1006 ± 7	U–Pb z D/LI	SH, MLT	Grenvillian metamorphism	2
1281	U–Pb t C	mfgn, LJT	Uncertain	2
1452^{+15}_{-13}	U–Pb b D/UI	SH, MLT	Igneous crystallization age	1
1459^{+23}_{-22}	U–Pb z D/UI	SH, MLT	Igneous crystallization age	2
1606^{+7}_{-5}	U–Pb m D/LI	pgn, LJT	Leucosome formation	2
1619 ± 2	U–Pb z C	grnt, LJT	Igneous age of metacrystic granite	4
1623^{+7}_{-5}	U–Pb z D/UI	OMIS, LJT	Igneous crystallization age	2
1636^{+5}_{-4}	U–Pb m D/UI	pgn, LJT	Leucosome formation	2
1639 ± 2	U–Pb z,r D/UI	OMIS, LJT	Igneous crystallization age	1
1647, 1645	U–Pb z C	grnt, LJT	Labradorian metamorphism	3
1648 ± 7	U–Pb z D/UI	TLb, MLT	Igneous crystallization age	2
1660 ± 5	U–Pb m D/UI	pgn, LJT	Leucosome formation	2
1660 ± 5	U–Pb t,z D/UI	grn gns, LJT	Igneous crystallization age	1
1672	U–Pb	grnt, LJT	Igneous crystallization age	3

Systematics:

U–Pb–uranium–lead isotopic system, z–zircon, t–titanite, r–rutile, b–baddelyite, m–monazite, C–concordant, D/UI–discordant, upper intercept, D/LI–discordant, lower intercept.

Lithology:

SH–Shabogamo Gabbro, TLb–Trans-Labrador batholith, peg–pegmatite, grn gns–granitoid gneiss, mfgn–mafic supracrustal gneiss, grnt–granitoid intrusions, OMIS–Ossok Mountain intrusive suite, pgn–metamorphic leucosome in paragneiss, MLT–Molson Lake terrane, LJT–Lac Joseph terrane.

References:

1–Appendix 1 and J. Connelly (personal communication, 1993), 2–Connelly and Heaman (1993), 3–Krogh (1983), and 4–Brooks (1983).

Based on U–Pb geochronological studies, Connelly *et al.* (1990) and Connelly and Heaman (1993) have concluded that the Lac Joseph terrane was emplaced on terranes to the north between approximately 1000 to 980 Ma. This is essentially synchronous with medium- to high-grade Grenvillian metamorphism and penetrative deformation in the Churchill Falls and Molson Lake terranes as determined from U–Pb geochronological studies (Rivers and Nunn, 1985; Connelly *et al.*, 1990).

These structural and metamorphic relations in Grenvillian high-strain structures are consistent with geochronological data that suggest terrane accretion was synchronous with Grenvillian metamorphism. However, peak Grenvillian metamorphic pressures in the footwall rocks, west of the Lac Joseph terrane, are estimated to locally exceed 15 kbars (Indares, 1993; and see Connelly *et al.*, 1989; Indares, 1991). The fact that the Lac Joseph terrane was not exposed to this high-pressure metamorphism or regionally pervasive penetrative deformation in the Grenville Orogeny, but was accreted to the structurally lower terranes at approximately the same time as amphibolite-facies Grenvillian metamorphism, indicates rapid uplift of the structurally lower terranes prior to terminal emplacement of the Lac Joseph terrane. Rapid exhumation and erosion of footwall rocks followed by emplacement of the Lac Joseph terrane at a relatively high crustal level could explain how the Lac Joseph terrane escaped Grenvillian, high-pressure metamorphism, and was only locally metamorphosed to amphibolite-facies in areas along their mutual contact during Grenvillian accretion.

DESCRIPTION OF ROCK UNITS

PARAGNEISS

Contact Relations and Age

A unit consisting of high-grade migmatitic paragneiss (Plate 1) underlies a significant portion of the Lac Joseph terrane and also outcrops on an island in Ossokmanuan Lake (UTM coordinates 355500 E, 5925800 N) in an area that is defined as being within the Molson Lake terrane. The latter occurrences of paragneiss could either be interpreted as a structurally bound slice of Lac Joseph terrane rocks, or they could be an inherent part of the Molson Lake terrane, perhaps occurring as an inclusion in Trans-Labrador batholith rocks.

Plate 1. *Typical field aspects of migmatitic paragneiss. Photo DJ-90-2317.*

All rock units within the Lac Joseph terrane intrude the paragneiss unit with the exception of mafic supracrustal gneiss, which is locally interlayered with it. On this basis, the paragneiss is inferred to be the oldest unit in the study area. Contacts between the paragneiss and the mafic supracrustal gneiss are not exposed, although layers of semipelitic to psammitic paragneiss that occur within the mafic supracrustal gneiss unit proper, suggest that the contact is gradational, reflecting an original sedimentary–mafic volcanic(?) interlayering.

Local occurrences of mafic rocks are interlayered with the paragneiss unit throughout the Lac Joseph terrane. Most of these minor occurrences of mafic rocks, which are too small to be shown on the map, are similar to the mafic supracrustal gneiss unit, although some are of uncertain origin and could be pre-Labradorian mafic dykes (Plate 2).

Plate 2. *Metamorphosed and deformed pre-Labradorian mafic dyke in migmatitic paragneiss. Photo DJ-90-1115.*

The paragneiss is intruded by the Ossok Mountain intrusive suite. Contacts between the two units are commonly transitional, consisting of a zone that is locally several hundred metres wide and composed of paragneiss having a profusion of mafic intrusions, and mafic intrusive rocks having abundant, lenticular paragneiss xenoliths. Rarely, the units are separated by a sharp, intrusive contact.

Paragneiss is locally intruded by mafic dykes that are correlated with the Ossok Mountain Suite on the basis of rock

type. The dykes are metamorphosed to high grade, but are discordant to the Labradorian gneissosity in the paragneiss unit (Plate 3). These relations demonstrate that Ossok Mountain intrusions postdate, at least locally, the formation of Labradorian gneissosity in the paragneiss, and suggest that the Labradorian thermal peak outlasted the main Labradorian deformation and the Ossok Mountain intrusive event.

Plate 3. *Recrystallized mafic dyke containing stable orthopyroxene. The dyke is discordant to the high-grade fabric elements in migmatitic paragneiss. Photo DJ-90-1010.*

The paragneiss is presumed to be intruded by the granitoid units composed of granite, including minor quartz monzonite and monzodiorite, and charnockite–mangerite, although contacts were not observed. The granitoid units have not been radiometrically dated.

The minimum depositional age of paragneiss in the Lac Joseph terrane is constrained by the age of Labradorian metamorphism, dated by U–Pb methods to be in the approximate range 1660 to 1635 Ma (Krogh, 1983; Connelly *et al.* 1990; Connelly and Heaman, 1993). East of the Lac Joseph terrane, however, U–Pb ages of metamorphic zircons are consistently older, falling in the range 1676 to 1700 Ma (e.g., Krogh, 1983; Currie and Loveridge, 1985; Thomas *et al.*, 1986). The depositional age of paragneiss is further constrained by the Susan River quartz diorite, which intrudes paragneiss in the eastern end of the Metasedimentary Gneiss terrane, and dated by U–Pb methods to be 1672 $^{+11}_{-10}$ Ma (Philippe *et al.*, 1993).

The maximum depositional age is unconstrained by field relations, although U–Pb zircon studies of paragneiss from the Lac Joseph terrane by Connelly and Heaman (1993) indicate an Early Proterozoic, ca. 1900 to 1800 Ma, sedimentary provenance. In addition, Fryer (1983) and Kerr *et al.* (1992) have argued on the basis of Rb–Sr and Nd isotopic studies that rocks in the Metasedimentary Gneiss terrane are Early to Middle Proterozoic, and were possibly deposited in the interval 1.9 to 1.7 Ga. These data are consistent with isotopic studies by both Schärer *et al.* (1986) and Ashwal *et al.* (1986) that suggest Labradorian crust is primarily juvenile.

There is some data to suggest that the sediments contain an older component. Krogh (1983) and Thomas *et al.* (1986) report Archean, U–Pb zircon upper intercept ages for discordant zircons from the paragneiss, demonstrating the sediments incorporated at least some component of Archean detritus.

The sediments may be derived from Lower Proterozoic volcanic rocks in the Makkovic Province or from volcanic rocks in the Labrador Trough. Further isotopic studies are required to determine if the sediments were derived from a single or multiple source areas. These studies may show that the Metasedimentary Gneiss terrane is itself a collage of sedimentary rocks derived from fundamentally different sources.

Lithology

The paragneiss is homogeneous and monotonous, consisting mainly of pink- and grey-weathering or, rusty-weathering quartzofeldspathic migmatite containing biotite and magnetite, and commonly having aluminum silicate and garnet. Locally, rocks contain cordierite. There are several occurrences of rocks that contain orthopyroxene.

The unit contains two phases of K-feldspar-bearing leucosome including a grey-weathering phase and a slightly coarser grained, pink-weathering phase. The amount of leucosome present varies between 30 and 100 percent, but it is generally less than 60 percent. Commonly, both phases are completely transposed about the principal foliation, but in lesser strained rocks the pink phase clearly postdates the grey phase. Connelly and Heaman (1993) have dated monazites from the two leucosomes, obtaining U–Pb ages of 1660 ± 5 Ma for the grey phase and 1636 $^{+5}_{-4}$ Ma for the pink phase. Thus, both leucosomes are products of Labradorian high-grade metamorphism. The paleosome is composed of variable amounts of biotite, quartz, plagioclase and commonly sillimanite or kyanite, and garnet.

Sillimanite occurs as either fine-grained, grey-weathering needles or fibrolite aggregates, or as medium- to coarse-grained, white- to blue-weathering ovoid sillimanite–quartz porphyroblasts. Kyanite is commonly fine grained, and prismatic. Garnet is common in aluminum silicate-bearing gneiss, occurring as medium- to coarse-grained, lavender-weathering porphyroblasts, and poikiloblasts that have biotite, sillimanite and magnetite inclusions. Minor amounts of pyrite occur locally.

The paragneiss unit includes a minor amount of grey- or rusty-weathering quartzofeldspathic (psammitic) gneiss. The rocks have less than 15 percent biotite and may contain minor garnet and orthopyroxene. Locally, these rocks are interlayered with mafic gneiss and grey-weathering quartz-rich foliate (Ashton and Leclair, 1990) interpreted to be derived from quartzite.

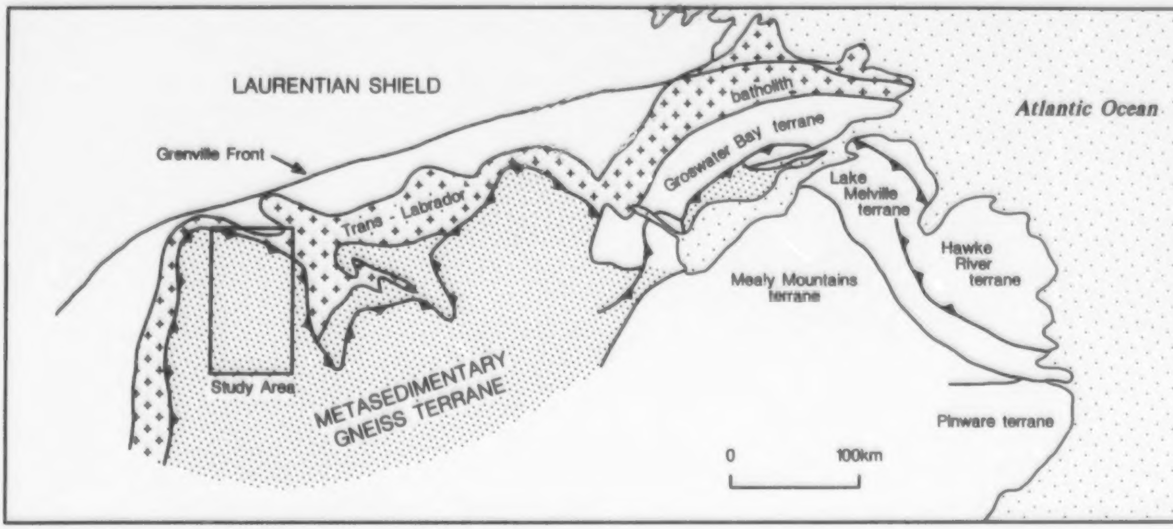


Figure 5. *The Metasedimentary Gneiss terrane, northeastern Grenville Province (after Wardle* et al., *1991).*

Interpretation and Correlation

The paragneiss is inferred to be derived mainly from semipelitic and pelitic sedimentary rocks. It is provisionally correlated with lithologically similar and regionally extensive high-grade paragneiss, locally named the Disappointment Lake gneiss (Thomas, 1981), which has been mapped by Nunn and Christopher (1983) in the Churchill Falls terrane, and by Wardle *et al.* (1986), Thomas and Blomberg (1990) and Wardle *et al.* (1990 and references therein) in the Wilson Lake terrane. Collectively, these occurrences of paragneiss make up a linear, but structurally imbricated, 400-km-long, northeast-trending supracrustal gneiss belt (Figure 5) termed the Metasedimentary Gneiss terrane (Wardle *et al.* 1991). However, stratigraphic linkages between different terranes and stratigraphic continuity within terranes remain to be firmly established and it is possible that the Metasedimentary Gneiss terrane contains a tectonic collage of paragneisses of significantly different age and provenance.

MAFIC SUPRACRUSTAL GNEISS

Interlayered with paragneiss in the Lac Joseph terrane are a few occurrences of a mafic gneiss unit that consists mainly of two-pyroxene gneiss, minor amounts of semipelitic paragneiss and rare, psamitic metasedimentary rocks and metamorphosed siliceous carbonate. The association of rock types and contact relations, both within the mafic gneiss unit and with the paragneiss unit, suggests that the mafic gneiss is derived from a supracrustal protolith, possibly a mafic volcanic unit, which is approximately the same age as the paragneiss.

Lithology

East and northeast of Lac Joseph, the mafic supracrustal gneiss is relatively common, and makes up several layers that are mappable at 1:100 000 scale. The mafic rocks in this area are black or black and rusty-weathering, and well-layered (Plate 4). Gneissosity is defined by variations in amounts of mafic minerals, and locally, by tonalitic leucosome that makes up to 20 percent of outcrops. The leucosome locally contains biotite and garnet. The paleosome is composed of variable amounts of orthopyroxene, clinopyroxene, hornblende, plagioclase, minor amounts of both biotite and quartz, and local garnet. Hornblende is present in variable amounts and commonly occurs as fine-grained rims around the pyroxenes or as medium-grained, spongy-textured poikiloblasts that appear to pseudomorph pyroxene. Biotite also appears to have grown at the expense of pyroxene. Pyroxene may also show the effects of low-grade replacement by bastite and carbonate. Rocks contain accessory pyrite, opaque, apatite, and zircon.

Plate 4. *Typical field aspects of mafic supracrustal gneiss. Photo DJ-90-2156.*

Mafic supracrustal gneiss also outcrops on islands in the southwest corner of Lac Joseph, and forms an approximately

500-m-thick layer of mafic gneiss and migmatite. In this area, the mafic supracrustal gneiss is in tectonic contact with the margin of a tectonic window that exposes Molson Lake terrane rocks through the Lac Joseph terrane, and in inferred stratigraphic contact with paragneiss to the west. Occurrences of highly strained mafic gneiss are common and are presumably the products of Grenvillian deformation related to terrane juxtaposition.

The mafic rocks at Lac Joseph are composed of layers consisting of variable amounts of hornblende, plagioclase, garnet, epidote, biotite, minor quartz, and rarely clinopyroxene. Locally, layering is defined by alternating hornblende-rich and plagioclase–epidote layers. The rocks contain approximately 30 percent tonalitic leucosome that occurs in layers and pods that are both structurally concordant and discordant with respect to the layering in the mafic rocks; the leucosome is locally garnet-bearing. Several outcrops have an agmatitic structure and contain >50 percent leucosome (Plate 5).

Plate 5. *Migmatized mafic supracrustal gneiss. Photo DJ-90-2318.*

At Lac Joseph, the unit also includes common occurrences of 1- to 5-m-thick layers of grey-, pink- or rusty-weathering paragneiss. The paragneiss is migmatitic, containing K-feldspar, biotite and variable amounts of muscovite. Muscovite forms randomly oriented, fine- to medium-grained plates and aggregates of plates that are discordant to both the principal foliation and ductile high-strain structures. The high-strain structures are interpreted to be Grenvillian in age, and on this basis the muscovite is inferred to be late Grenvillian.

In the Goose Bay region, an extensive unit of mafic gneiss, which occurs within the Metasedimentary Gneiss terrane and is inferred to have a supracrustal protolith, is termed the Beaver gneiss (Emslie *et al.*, 1978; Thomas *et al.*, 1983). Mafic supracrustal gneiss in the Lac Joseph terrane may be correlative with the Beaver gneiss.

TRANS-LABRADOR BATHOLITH

Contact Relations and Age

In the Molson Lake terrane, variably recrystallized and deformed, equigranular to megacrystic granite and local granite gneiss are correlated with the rocks of the Trans-Labrador batholith as defined by Wardle *et al.* (1986). Trans-Labrador batholith rocks in the study area can be traced to the east into the regionally extensive occurrences of Trans-Labrador batholith granite and granitoid gneiss mapped by Nunn and Christopher (1983) (and see Nunn, 1990) in the Churchill Falls terrane, and to the west and south into the extensive occurrences in the southwestern Molson Lake terrane (Connelly and Nunn, 1988).

Several occurrences of granitoid gneiss occur within the tectonic window through the Lac Joseph terrane at Lac Joseph. These rocks are correlated with the Trans-Labrador batholith based on similarity of rock types and inferred tectonic position.

In the Churchill Falls terrane, east of the study area, Trans-Labrador batholith rocks intrude Labradorian paragneiss (Nunn *et al.*, 1983; Nunn, 1990), which is inferred to be correlative with the paragneiss unit in the Lac Joseph terrane. This relation is not observed in the study area. Trans-Labrador batholith rocks in the Molson Lake and Churchill Falls terranes are intruded by mafic rocks of the Shabogamo Gabbro.

U–Pb zircon dating of Trans-Labrador batholith rocks, which occur outside of the present study area, indicate igneous ages that are ca. 1650 Ma (e.g., Brooks, 1983; Krogh, 1983; Thomas *et al.*, 1985; Nunn *et al.*, 1985; Connelly *et al.*, 1990; Connelly and Heaman, 1993).

Lithology

Trans-Labrador batholith rocks vary from syenogranite to rare tonalite, and from monzogranite to monzonite. Monzogranite and quartz monzonite are the most common rock types in the study area. Contact relations between the different rock types in the unit are indefinite. All components are intruded by local syenogranite dykes. Locally, the granitic rocks contain mafic xenoliths of uncertain origin.

The unit is texturally varied, ranging from rocks that have relict megacrystic and equigranular, isotropic igneous textures, to recrystallized, granoblastic metamorphic textures. Most commonly, rocks are medium to coarse grained, variably foliated, and have 1- to 2-cm-long, K-feldspar phenocrysts. Locally, foliated porphyritic rocks grade into megacrystic granite having 10- to 15-cm-long, concentrically zoned K-feldspar megacrysts (Plates 6 and 7). Recrystallized and strongly foliated K-feldspar augen gneiss is also gradational with the megacrystic rocks (Plate 8). Significant textural and structural variations can occur over several metres in a single outcrop.

Plate 6. *Outcrop photograph of K-feldspar megacrystic granite (Trans-Labrador batholith) at Ossokmanuan Lake. Photo DJ-90-2364.*

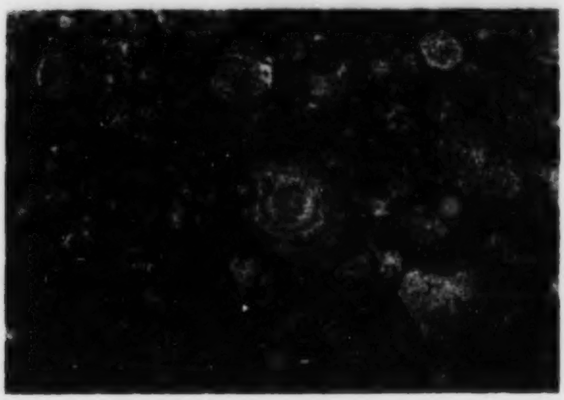


Plate 7. *Detailed close-up photograph (Plate 6) of K-feldspar megacrystic granite (Trans-Labrador batholith) at Ossokmanuan Lake. Photo DJ-90-2364.*

The rocks are composed of variable amounts of microcline, plagioclase, quartz, biotite, and local hornblende and garnet. Mafic minerals make up ≤10 percent of the rocks. Clinopyroxene occurs in a few rocks as relict cores armoured by hornblende, which is inferred to be of metamorphic origin based on this texture. Locally, rocks contain biotite and muscovite. Accessory magnetite, apatite, epidote, sphene and zircon are common.

The unit also has rocks with migmatitic structure. They include pink and grey-weathering granitoid migmatite gneiss and grey-weathering, tonalite migmatite. Locally, the migmatites contain two phases of deformed leucosome, including an older, fine-grained, grey-weathering phase and a younger, coarser grained, pink-weathering phase.

The age of the metamorphic minerals and the gneissosity is somewhat equivocal. These rocks were last metamorphosed to at least middle amphibolite-facies in the Grenvillian Orogeny, but it is possible that they were also brought to medium- or high-grade in the Labradorian Orogeny. Therefore, some of the metamorphic gneissosity in the Trans-Labrador batholith rocks could be a relict Labradorian feature.

Plate 8. *Photograph showing the gradational relationship between foliated K-feldspar megacrystic granite (top) and strongly foliated augen gneiss (bottom). Photo DJ-90-2375.*

GRANITOID GNEISS

Granitoid gneiss and migmatite, interpreted to be derived from plutonic rocks whose igneous age predates Labradorian metamorphism, are scattered throughout the Lac Joseph terrane. A contact is drawn around four, relative closely spaced outcrops of granitoid gneiss and migmatite in the central part of the study area, but the exposure in this area is so poor that the contact must be regarded as speculative only. There is little outcrop control or geophysical data to constrain the size and shape of this granitoid gneiss body.

U–Pb studies of zircon and titanite from this unit gave an upper intercept age of 1660 ± 5 Ma (Figure 6, and Appendix 1), which is interpreted to be the age of igneous crystallization. The igneous age suggests that the rocks may be the gneissic equivalents of a Trans-Labrador batholith-related intrusion. The lower intercept age of 1001 ± 7 Ma is thought to represent the age of Grenvillian metamorphism.

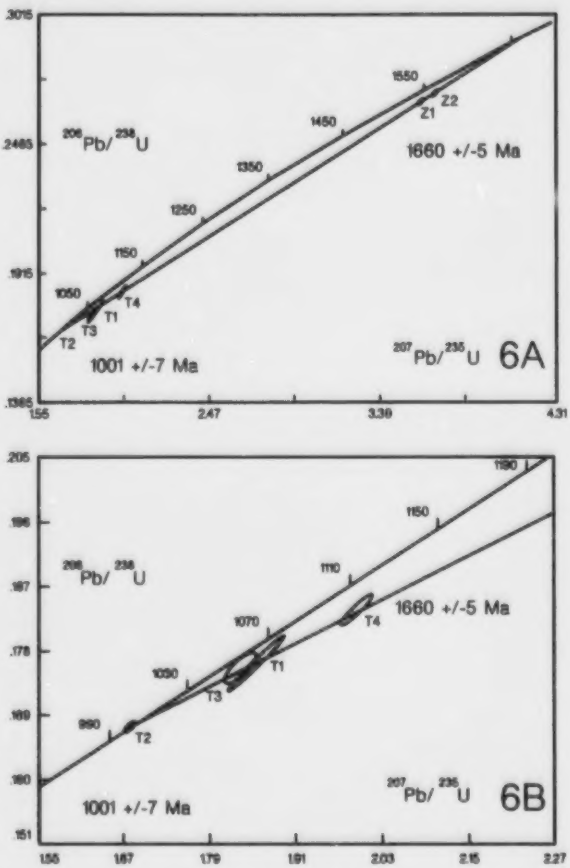


Figure 6. *Pb−U concordia diagram for a sample of granitoid gneiss, Lac Joseph terrane (sample DJ-90-2297). Figure 6B is a detailed view of the titanite data, which plots near the lower intercept shown in Figure 6A (data from Connelly, 1992).*

The rocks are grey and white-, black and white-, or white and pink-weathering tonalite to granodiorite gneisses that have gneissosity defined by alternating mafic and quartzofeldspathic layers. The rocks are composed of variable amounts of plagioclase, microcline, quartz, biotite, hornblende, and local garnet. Accessory epidote and sphene are common.

OSSOK MOUNTAIN INTRUSIVE SUITE

All mafic intrusive rocks in the Lac Joseph terrane, which are metamorphosed and are of presumed Labradorian age, are defined as belonging to the Ossok Mountain intrusive suite. The suite is a composite unit, consisting of a multitude of intrusive phases that are distinguished on the basis of cross-cutting, intrusive relationships. At this scale of mapping, however, individual units within the suite could not be separated. The suite is composed mainly of metamorphosed and deformed gabbronorite and lesser amounts of norite, gabbro, and local olivine gabbronorite and norite. Anorthosite is uncommon.

Metamorphosed mafic intrusive rocks have been mapped elsewhere in the Lac Joseph terrane by Nunn and Christopher (1983), Rivers (1985c), and Nunn (1990), and these are correlated with the Ossok Mountain intrusive suite. Similar suites of metamorphosed mafic intrusive rocks occur throughout the Labradorian high-grade terranes in the Grenville Province in Labrador (see Wardle *et al.*, 1986), and these are tentatively correlated temporally with the Ossok Mountain intrusive suite.

Ossok Mountain intrusive suite rocks occur throughout the Lac Joseph terrane, but they appear to be most abundant in the northern part of the terrane, in the areas adjacent to the tectonic contact with the Molson Lake terrane. There is a casual correspondence with the increase in abundance of the mafic intrusive rocks with higher pressure mineral assemblages in the paragneiss. This apparent correspondence suggests that distribution of the Ossok Mountain intrusive suite rocks may be a function of Labradorian paleodepth, where the relatively deep Labradorian crustal levels have more abundant mafic intrusions.

Contact Relations and Age

The Ossok Mountain intrusive suite intrudes paragneiss in the Lac Joseph terrane. The larger bodies of the unit are thought to form sheet-like intrusions that are estimated to be up to 2 km thick (Figure 7), although small bodies and dykes, too small to be shown on the map, are common.

The Ossok Mountain intrusive suite is intruded by dykes of granite and megacrystic granite. The dykes are deformed and metamorphosed, presumably by Labradorian-age events, and are correlated on this basis with other inferred Labradorian-age metamorphosed granite units mapped in the Lac Joseph terrane.

U−Pb zircon analysis of a coarse-grained gabbro from the Ossok Mountain intrusive suite yielded a nearly concordant age of 1639 $\pm$ 2 Ma (Figure 8, and Appendix 1). This is thought to represent the age of igneous crystallization. U−Pb zircon geochronology by Connelly and Heaman (1993) of a medium-grained, massive gabbronorite occurring in the Lac Joseph terrane west of the study area (in NTS map area 23G/1), and presumed to be correlative with the Ossok Mountain intrusive suite, yielded an age of 1623 $^{+7}_{-5}$ Ma, interpreted to be the age of igneous crystallization.

Lithology

The unit is composed mainly of metamorphosed and variably deformed and recrystallized gabbronorite and lesser amounts of gabbro, norite, and olivine-bearing rocks (Plates 9, 10 and 11). Anorthosite and pyroxenite are minor. The unit

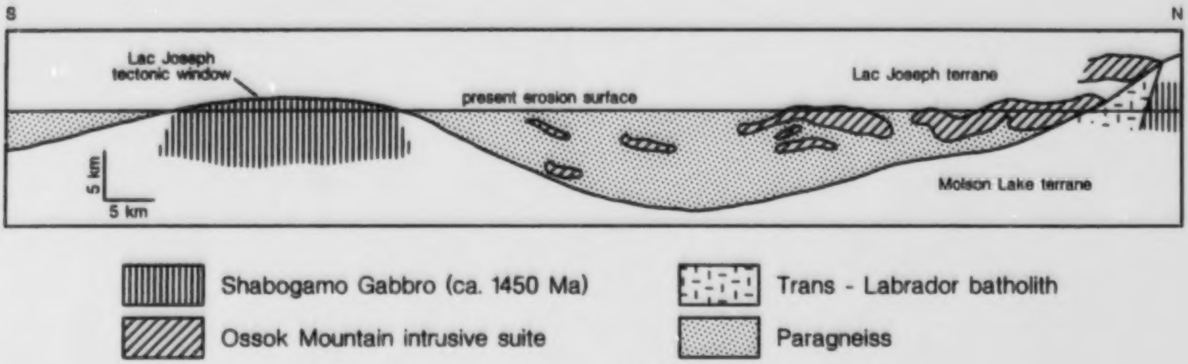


Figure 7. *Schematic north-south section through the Lac Joseph terrane showing distribution and inferred shape of Ossok Mountain intrusions.*

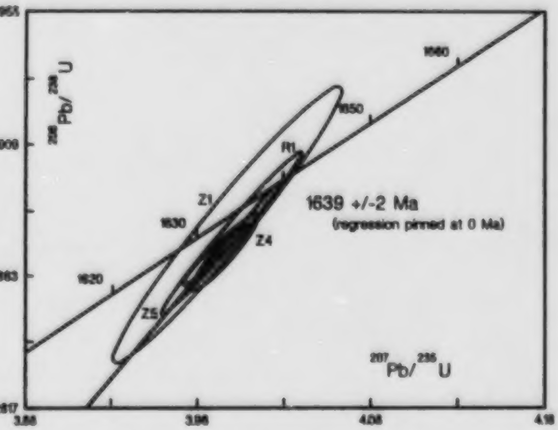


Figure 8. *Pb−U concordia diagram for a sample of gabbronorite from the Ossok Mountain intrusive suite (sample DJ-90-0010; after Connelly, 1992).*

Plate 9. *Recrystallized and weakly foliated gabbronorite. Photo DJ-90-2040.*

also contains a minor amount of conspicuously well-layered mafic gneiss that occurs around the margins of some of the intrusions.

Plate 10. *Anorthositic gabbro containing relict intergranular texture. Photo DJ-90-0204.*

Plate 11. *Coarse-grained, olivine gabbronorite. Photo DJ-90-3055.*

The unit is texturally inhomogeneous at all scales, containing rocks that vary from fine grained and completely recrystallized and having no relict igneous textures, to rocks that are medium to coarse grained containing preserved

igneous plagioclase laths and interstitial pyroxene. In the field, it can be locally demonstrated that coarser grained gabbronorite, containing relatively well-preserved igneous textures, intrudes finer grained rocks that have a granoblastic, metamorphic texture. These local relationships probably cannot be applied to the Ossok Mountain intrusive suite as a whole, and it is probable that there are also gradational relationships between rocks having recrystallized, metamorphic textures and rocks having relict igneous textures. Locally, the suite contains rocks having igneous cumulate layering and plagioclase lamination fabrics.

All rock types in the suite and in the paragneiss unit are cut by fine-grained, recrystallized gabbronorite dykes (Plate 12). The dykes are included in the Ossok Mountain intrusive suite on the basis of composition and degree of recrystallization.

Plate 12. *The dyke in this photograph has a granoblastic, metamorphic texture and contains metamorphic orthopyroxene and plagioclase. The dyke is discordant to the high-grade planar fabric in the host gabbronorite. Photo DJ-90-4018.*

Most of the rocks in the Ossok Mountain intrusive suite display signs of amphibolite-facies retrogression. The age(s) and significance of the retrogression are discussed in the section on Metamorphism (page 37).

Gabbronorite, Gabbro and Norite

The most common rock type in the Ossok Mountain intrusive suite is a recrystallized and variably foliated gabbronorite that makes up more than 60 percent of the suite. Texturally similar gabbro and norite occur locally, and they are interpreted to be gradational with the gabbronorite. Norite is more abundant than gabbro. The rocks are mainly equigranular and granoblastic, and composed of varied proportions of orthopyroxene, clinopyroxene and plagioclase. Rocks contain minor ilmenite, biotite, hornblende, accessory apatite and rare garnet. Quartz-bearing rocks are uncommon.

Orthopyroxene, clinopyroxene and plagioclase (An_{30-70}) are fine to medium grained, but are most commonly less than 1 mm in diameter. These minerals form a granoblastic (metamorphic) texture and this, along with their stable coexistence, indicates that recrystallization of the rocks was concomitant with Labradorian high-grade metamorphic conditions. The rocks also contain local relict outlines of igneous plagioclase or pyroxene grains that are variably pseudomorphed by granoblastic aggregates of plagioclase or pyroxene, respectively. Margins of pyroxene grains are variably overprinted by biotite $\pm$ hornblende. Rarely, garnet occurs as a fine-grained phase throughout the rock or as a corona around an opaque mineral (ilmenite?).

Less commonly, the gabbronorite, gabbro, and norite are medium to coarse grained and contain relict interstitial pyroxene and lath-shaped, igneous plagioclase grains that locally define an igneous lamination. Accessory ilmenite as inclusions in pyroxene grains, fine-grained opaque, and apatite are common.

Olivine Gabbronorite

Olivine gabbronorite and norite make up a subordinate amount of the unit. The rocks are medium to coarse grained with subhedral- to anhedral-granular textures. No olivine was observed in rocks that had a strong foliation, or that were extensively recrystallized, suggesting that strain and attendant recrystallization enhanced the conversion of olivine to orthopyroxene. The percentage of olivine present is varied, but it is generally ≤ 25 percent. The remainder of the rocks consist of pyroxenes and plagiocalse. Spinel is a common constituent.

The olivine crystals have been varaibly replaced by a composite corona consisting of an inner corona of fine-grained, granular or bladed orthopyroxene, and an outer corona of cloudy to green, vermiculated clinopyroxene-spinel symplectite (Plate 13). The inner, orthopyroxene corona is of varied width, and locally, granular or bladed orthopyroxene has completely pseudomorphed the olivine. The outer, vermiculated corona is generally less than 1 mm wide. The outer corona can also have inclusions of fine-grained, granular orthopyroxene, and fine-grained, green spinel that has its own biotite corona, which is included entirely within the vermiculated corona. Locally, the inner orthopyroxene rim is absent and the vermiculated corona is in direct contact with the olivine. Where this occurs, the olivine-vermiculated corona contact is marked by very fine-grained magnetite and/or spinel. Low-grade pseudomorphing of olivine by serpentine is locally developed.

This corona texture has been described by Rivers and Mengel (1988), and they propose that it is a single-stage, Labradorian feature, formed during isobaric cooling following emplacement. This conclusion is consistent with the observation that the coronitic rocks are massive and preserve igneous textures, suggesting they mainly escaped Labradorian recrystallization because of their character (i.e., they may have been too dry, massive and coarse grained to be amenable to Labradorian recrystallization), or that their emplacement postdated Labradorian metamorphism and deformation.

Plate 13. *Photomicrograph of corona texture in olivine gabbronorite, Ossok Mountain intrusive suite. Olivine (olv) has a rim of bladed orthopyroxene (opx) and an outer rim of dusty, clinopyroxene spinel semplectite (cpx/spi). Photo DJ-90-2027.*

Plate 14. *Typical field aspects of well-layered, two-pyroxene and garnet gneiss, which occurs around the margins of some of the intrusions of the Ossok Mountain intrusive suite. Photo DJ-90-0135.*

The Ossok Mountain intrusive suite includes occurrences of mela-troctolite at Lac Pas d'Eau, in the southern part of the study area, and northeast of Lac Joseph. The rocks at Lac Pas d'Eau are non-foliated, and form a cumulate-layered outcrop. Rocks are black-weathering, fine to medium grained and have an adcumulate texture defined by fresh, subhedral olivine grains that are surrounded by coarser grained plagioclase.

The occurrence of mela-troctolite northeast of Lac Joseph (UTM coordinates 365450 E, 5865900 N) appears to form a northwest-striking dyke in the paragneiss unit, and is tentatively correlated with the Ossok Mountain intrusive suite. (Contacts with the surrounding rocks are not exposed.) The rocks are brown-weathering, fine grained and are composed mainly of serpentine that has pseudomorphed olivine. Less than 15 percent of the rock is relict olivine. Chemical analysis of samples from this outcrop indicate somewhat anomalous nickel but low chromium (see Table 4, page 42, and Economic Geology section, page 42).

Mafic Gneiss

Mafic gneiss, which occurs around the margins of some of the larger intrusions of the Ossok Mountain intrusive suite, makes up a minor part of the suite. The gneiss is well layered, consisting of 1- to 15-cm-thick layers defined by variations in the amount of mafic minerals (Plate 14). Some of the layers appear to consist of metamorphosed and deformed mafic dykes that have been completely transposed. Locally, the mafic gneiss contains a minor amount of mafic agmatite consisting of blocks of pyroxenite surrounded by tonalite leucosome.

The mafic gneiss is composed of variable amounts of hornblende, plagioclase, clinopyroxene and garnet, and minor amounts of quartz and opaque minerals. Clinopyroxene is variably replaced by hornblende. Accessory calcite, scapolite and sphene are common.

GRANITE

Contact Relations and Age

The Lac Joseph terrane includes two granitoid plutons that are variably deformed and recrystallized. They are composed of K-feldspar megacrystic granite, locally having rapakivi texture, and lesser amounts of quartz monzonite, granodiorite and rare tonalite. On the basis of similarity of rock types and textures, these two plutons are tentatively correlated. The plutons are very poorly exposed and the locations of the contacts with the surrounding rocks are not tightly constrained.

Both plutons lie within the paragneiss unit, hence the contact relations with the other rock units in the Lac Joseph terrane are undefined. The pluton north of Lac à l'Eau-Claire surrounds several occurrences of gabbro; these are either xenoliths or intrusions of Ossok Mountain intrusive suite rocks. Critical contact relations are unexposed.

Dykes of granite and megacrystic granite, which have similar compositions and textures as some of the rocks in the plutons, unequivocally intrude components of the Ossok Mountain intrusive suite. This relationship demonstrates that there is a granitic intrusive event that postdates the Ossok Mountain intrusive suite, although a definitive correlation between the dykes and the plutons cannot be demonstrated in the field.

Elsewhere in the Lac Joseph terrane, Brooks (1983) reports a U–Pb zircon age of 1619 Ma, inferred to be the age of igneous intrusion, for a metamorphosed megacrystic granite that occurs in NTS map area 23G/09E. Krogh (1983)

and Thomas *et al.* (1986) report a U–Pb zircon age of 1672 Ma, interpreted to be the possible age of emplacement, from a granulite-facies monzogranite that occurs east of the study area in NTS 23H/02. The metamorphosed and foliated granitic rocks in the present study area are thought to have igneous ages within this broad age range.

Lithology

The granites are mainly pink- to grey-weathering and display megacrystic textures, containing relict K-feldspar phenocrysts, and recrystallized, equal-grained, granoblastic textures. Monzogranite and granodiorite are the most common rock types.

The megacrystic rocks have 15 to 20 percent microcline phenocrysts set in a fine-grained quartzofeldspathic matrix. Where recrystallization is extensive and the rocks are strongly foliated, an augen structure is developed from the feldspar phenocrysts. The megacrystic rocks are generally monzogranite, and contain biotite and local hornblende or orthopyroxene. The granoblastic textures and the presence of orthopyroxene demonstrate that recrystallization was concomitant with high-grade, Labradorian metamorphism. Garnet occurs locally in biotite- and biotite–hornblende-bearing rocks. Accessory opaque, apatite, tourmaline and zircon are common.

The equigranular rocks are mainly fine- to medium-grained granoblastic rocks that vary in composition from monzogranite to tonalite, and contain biotite and locally hornblende. Mafic minerals are locally replaced by chlorite, and muscovite overprints biotite and plagioclase.

Within the Lac Joseph terrane, several occurrences of olive green- to grey-weathering, fine-grained, recrystallized, orthopyroxene and biotite-bearing quartzofeldspathic rocks occur as dykes in the Ossok Mountain intrusive suite. These dykes, presumed to be granulite-facies granite dykes, may be related to the other orthopyroxene-bearing granitoid rocks in the Lac Joseph terrane.

CHARNOCKITE–MANGERITE

The Lac Joseph terrane contains a small charnockite–mangerite body, which outcrops approximately 10 km northeast of Lac à l'Eau-Claire. Only two outcrops were found, and contacts are approximated based on the pattern of magnetic anomalies, the charnockite–mangerite unit being slightly more magnetic than surrounding paragneiss. The unit has not been radiometrically dated, but the presence of orthopyroxene in the rocks suggests it is a pre- to syn-Labradorian intrusion.

The charnockite–mangerite is characteristically grey- to mauve-weathering. Rocks are medium to coarse grained and have a hypidiomorphic–granular texture. They are composed of K-feldspar, which is locally microperthitic, plagioclase, 10 to 20 percent quartz, and fine- to medium-grained clinopyroxene and orthopyroxene. Orthopyroxene occurs both as a separate phase in the rock and as local cores in some clinopyroxene grains. The unit also contains 5 to 10 percent, medium-grained biotite, which locally overgrows the pyroxene. The rocks are non-foliated and isotropic.

SHABOGAMO GABBRO

Contact Relations and Age

The Molson Lake terrane includes variably metamorphosed and deformed olivine gabbro, and lesser amounts of gabbronorite and rarely troctolite. These rocks occur in the Ossokmanuan Lake area, and they are inferred to underlie much of the Molson Lake terrane that is exposed in a structural window through the Lac Joseph terrane at Lac Joseph. On the basis of similarity of rock types, contact relations and age, these mafic intrusive rocks are correlated with the Shabogamo Gabbro.

In this report, the name Shabogamo Gabbro is used following Frarey and Duffell (1964), and later, Fahrig (1967). The name was changed by Rivers (1980) to Shabogamo Intrusive Suite to include mafic intrusive rocks and spatially associated granitoid rocks that occurred in western Labrador and were thought to be related. It has been subsequently shown that the granitoid rocks are significantly older than the gabbroic rocks, and unrelated to them, and on this basis, Gower *et al.* (1991a) suggested a reversion back to the name Shabogamo Gabbro. This reversion is adopted in this report.

In western Labrador, the Shabogamo Gabbro occurs in the southern part of the eastern Churchill Province and in the contiguous northern Grenville Province, including the Gagnon, Molson Lake and Churchill Falls terranes. To the east, the Shabogamo Gabbro is correlative with the Michael Gabbro (Stevenson, 1970; Fahrig and Larochelle, 1972; and see Gower and Owen, 1984; Ryan, 1984) based on similarities in their ages, geochemical signatures (Gower *et al.*, 1991a), and tectonic position along the northern margin of the Grenville Province. The Michael Gabbro has been dated by U–Pb zircon to be 1426 ± 6 Ma (Schärer *et al.*, 1986).

The Shabogamo Gabbro intrudes the Trans-Labrador batholith. Contacts appear to be sharp, but they are not commonly exposed. The Shabogamo Gabbro is significantly more magnetic than the granitic rocks of the Trans-Labrador batholith, and the contacts shown on the map are drawn with the aid of magnetic anomaly maps in the poorly exposed areas.

In the Lac Joseph area, the Shabogamo Gabbro has local xenoliths of dark-weathering, biotite- and garnet-bearing granitoid gneiss that may be derived from the Trans-Labrador batholith. Locally, the Shabogamo Gabbro is intruded by undeformed and unmetamorphosed pegmatites of inferred Grenvillian-age (Plate 15).

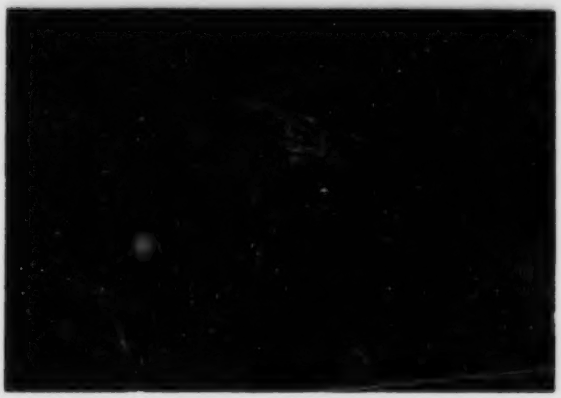


Plate 15. *Outcrop of Shabogamo Gabbro containing two sets of undeformed pegmatite dykes at Lac Joseph. The dykes are undeformed and unmetamorphosed and are inferred to be Grenvillian in age. Photo DJ-90-2333.*

A sample of Shabogamo Gabbro, collected from within the tectonic window at Lac Joseph, contained baddeleyite having overgrowths of zircon. Analysis of the baddeleyite and zircon yielded a U–Pb upper intercept age of 1452 $^{+15}_{-13}$ Ma and a lower intercept age of 966 $\pm$ 30 Ma (Figure 9, and Appendix 1). The upper intercept age indicates the igneous crystallization age, whereas the lower intercept indicates a metamorphic event that resulted in zircon crystallization around pre-existing baddeleyite. The igneous age is consistent with the 1459 $^{+23}_{-22}$ Ma age obtained from Shabogamo Gabbro, east of Labrador City (Connelly and Heaman, 1993).

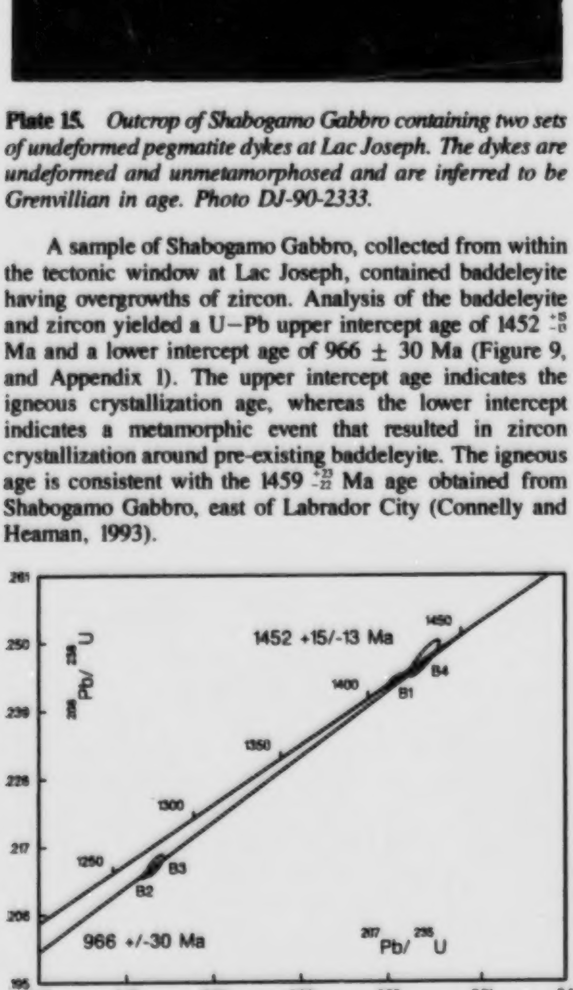


Figure 9. *Pb–U concordia diagram for a sample of Shabogamo Gabbro, which occurs at Lac Joseph (sample DJ-90-2303; after Connelly, 1992).*

Lithology

Ossokmanuan Lake Area

In the Ossokmanuan Lake area (Figure 10), the Shabogamo Gabbro consists mainly of black- to green-

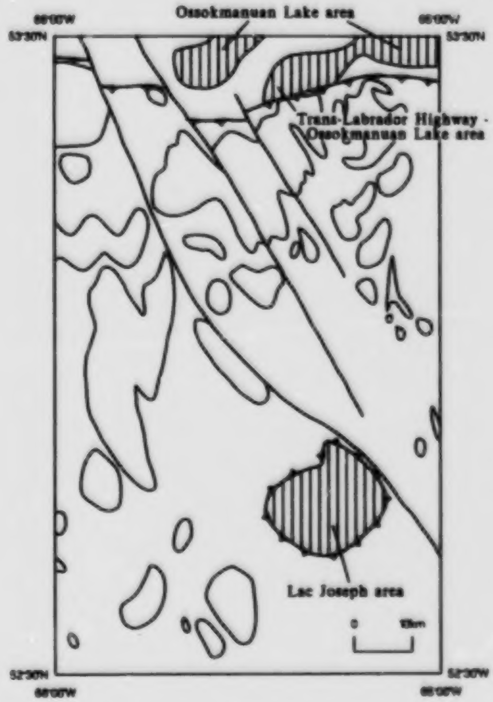


Figure 10. *Subdivision of the Shabogamo Gabbro in the study area.*

weathering olivine gabbro or gabbronorite. The unit includes minor occurrences of troctolite, and rarely, diorite. Occurrences of cumulate-layered rocks (Plates 16 and 17) and igneous lamination structure, defined by alignment of plagioclase laths, are relatively common. Outcrops locally consist of numerous, crosscutting phases of gabbro, but individual units could not be separated at this scale of mapping.

Plate 16. *Cumulate layered Shabogamo Gabbro. Photograph is from outcrop. Photo DJ-90-2035.*

The rocks are variably strained, from massive to mylonitic, and the effects of amphibolite-facies, Grenvillian

Plate 17. *Detailed view of the same outcrop shown in Plate 16, showing coarse-grained, intergranular texture. Photograph is from outcrop DJ-90-2035.*

metamorphism and low-grade retrogression are also displayed. The mineralogy and texture of the rocks vary from complete preservation of igneous mineralogy and texture, through multiple, amphibolite-facies coronas around the mafic minerals, to near-complete replacement of original, igneous mineralogy and texture by hornblende, biotite and garnet, and recrystallized plagioclase. In general, the rocks that are the most highly strained are also the most pervasively overprinted by amphibolite-facies minerals.

The most common rock type in the Ossokmanuan Lake area is an orthopyroxene ± olivine gabbro. Plagioclase laths are fine to coarse grained, and commonly have a grey-brown, cloudy appearance due to abundant, very fine-grained inclusions inferred to be corundum (see Rivers and Mengel, 1988; Gower *et al.*, 1991a). Pyroxene grains exhibit an intercumulus texture. Olivine grains are subrounded. Accessory ilmenite and apatite are common.

The area also contains a minor amount of pyroxene troctolite and leucotroctolite. These rocks are fine to medium grained with equant, anhedral olivine grains and ≤10 percent pyroxene that occurs as both intergranular grains and as a corona around olivine.

The Shabogamo Gabbro contains rocks that have both single and multiple coronas around olivine, pyroxene, and ilmenite. These structures, which have been studied in detail by Rivers and Mengel (1988), separate the mafic minerals from plagioclase (Plates 18, 19 and 20). The types of coronas include: 1) a single corona of green-yellow pargasitic amphibole (Rivers and Mengel, 1988) around olivine and pyroxene, 2) a single corona of garnet, which contains abundant biotite inclusions, that occurs around a clinopyroxene core, 3) a multiple corona around a core of cloudy, inclusion-rich clinopyroxene that consists of an inner corona of amphibole, itself containing inclusions of biotite and local fine-grained garnet, and a discontinuous outer corona of garnet, 4) a multiple corona structure consisting of an olivine core armoured by an inner corona of bladed

Plate 18. *An amphibole (amp) corona around bladed and granular orthopyroxene (opx) in Shabogamo Gabbro. The orthopyroxene also has a partial garnet (grt) corona, and garnet grains occur within the amphibole.*

Plate 19. *Photomicrograph of granular-textured orthopyroxene (opx), which is inferred to pseudomorph olivine. The orthopyroxene has a multiple corona of amphibole (amp) and garnet (grt).*

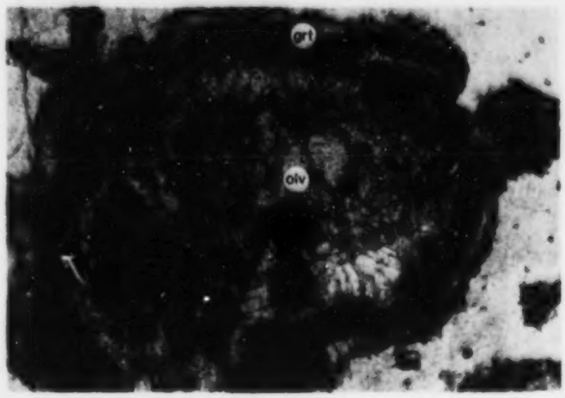


Plate 20. *Photomicrograph of olivine (olv), which has a garnet (grt) corona. The olivine and garnet are commonly separated by a thin opaque layer.*

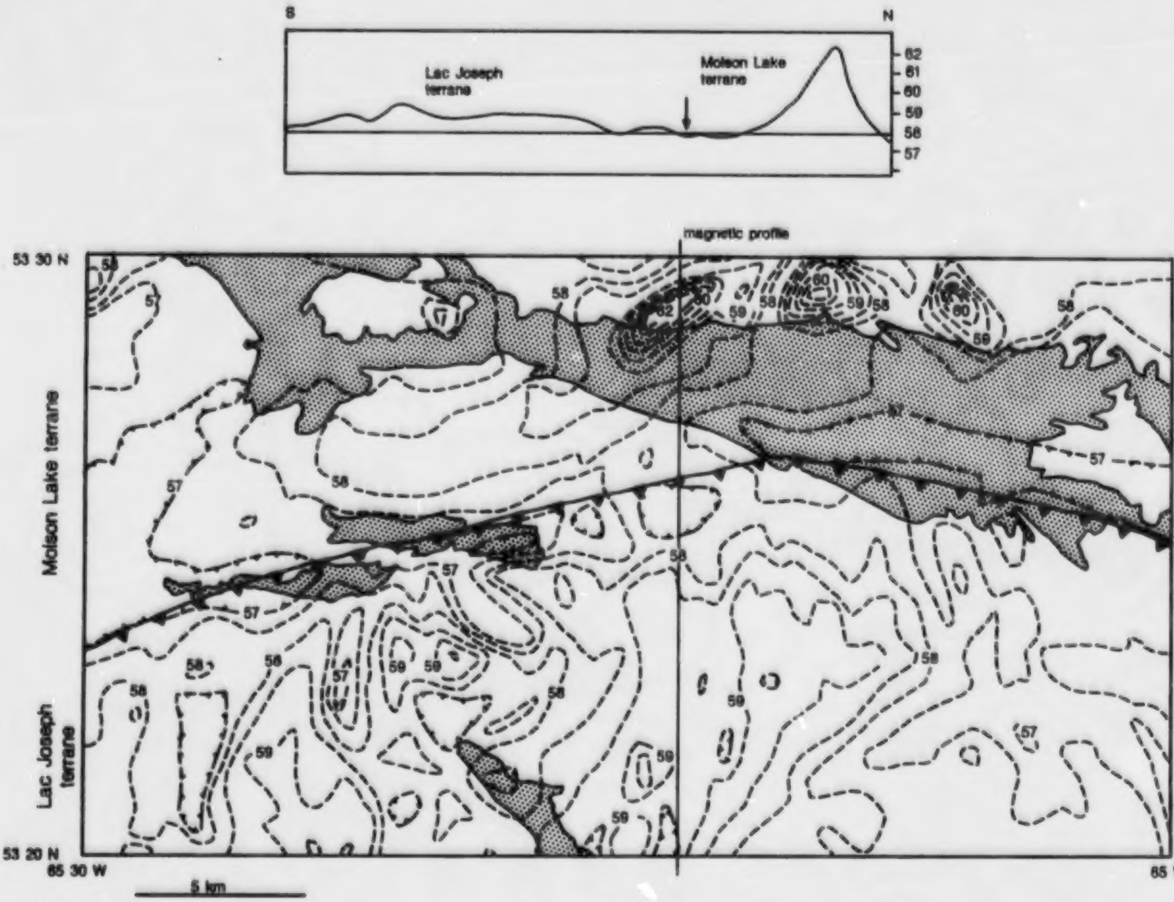


Figure 11. *Aeromagnetic anomaly map for the northeastern part of the study area. Contour labels are in gammas x1000. Contour interval is 500 gammas.*

or granular orthopyroxene, and an outer corona of garnet, 5) a single corona of biotite, or biotite–amphibole around ilmenite, and 6) a multiple corona of biotite (inner corona) and garnet (outer corona) armouring an ilmenite core. Garnet can also occur in the coronitic rocks as a non-corona phase, and locally makes up 15 to 20 percent of the rocks. Some rocks contain a minor amount of scapolite. Olivine is variably pseudomorphed by serpentine, magnetite and iddingsite. The age and significance of these coronas are discussed in the section on Metamorphism (page 37).

The occurrences of highly strained Shabogamo Gabbro are fine to medium grained and completely recrystallized producing a foliated amphibolite that contains garnet, biotite and hornblende (Plate 21). A minor amount of clinopyroxene is locally preserved in cores of hornblende. Plagioclase is completely recrystallized to a fine-grained, granoblastic plagioclase aggregate, and igneous grain shapes are obliterated.

Plate 21. *Strongly foliated, amphibolite-facies Shabogamo Gabbro from near the margin of the tectonic window at Lac Joseph. The foliation is defined by lenses of fine-grained, granoblastic plagioclase, and augen-shaped aggregates consisting of hornblende and clinopyroxene. Photo DJ-90-2306.*

Trans-Labrador Highway – Ossokmanuan Lake Area

In the northeast corner of the study area, between the

Plate 22. *Extensive, amphibolite-facies retrogression of massive Shabogamo Gabbro at Ossokmanuan Lake. The dark areas consist mainly of hornblende and plagioclase, whereas the light areas consist of garnet and plagioclase. Photo DJ-90-2366*

Trans-Labrador Highway and the south shore of Ossokmanuan Lake, Shabogamo Gabbro is commonly highly strained and extensively overprinted by amphibolite-facies minerals. Characteristically, the rocks in this area have neither relict igneous textures nor coronitic (metamorphic) textures that are common in lesser strained Shabogamo Gabbro that occurs at Ossokmanuan Lake and Lac Joseph. These textural differences were thought to be significant, and on this basis, the metamorphosed gabbro in this area was initially mapped as part of the Ossok Mountain intrusive suite (see Connelly, 1988; James *et al.*, 1991; James 1991). However, subsequent petrographic and geochemical studies of lesser strained rocks from this area suggest these mafic rocks should be correlated with the Shabogamo Gabbro and not the Ossok Mountain intrusive suite. This correlation is consistent with the regional pattern of regional magnetic anomalies, which are continuous from the north shore of Ossokmanuan Lake to near the Trans-Labrador Highway (Figure 11). Nevertheless, minor amounts of highly strained and retrogressed (to amphibolite facies) Ossok Mountain intrusive suite rocks could also occur in this area, in tectonic slices that are bound by highly strained Molson Lake terrane rocks.

The retrogression in the area is manifest in several forms. Where it is most extensive, the rocks are completely converted to fine- to medium-grained, granoblastic amphibolite schists or gneisses composed of hornblende, plagioclase, garnet, and minor biotite, quartz and scapolite. They contain accessory calcite, sphene, and apatite. Locally, a minor amount of clinopyroxene occurs as fine-grained cores in hornblende. Where amphibolite-facies retrogression and recrystallization is less extensive, the rocks retain some relict orthopyroxene and clinopyroxene that are variably overprinted by hornblende, biotite and garnet.

Locally, there is an anastomosing, 'fish-net' pattern of retrogression consisting of discontinuous layers and elliptical zones, composed of very fine-grained, granular garnet (>30 percent), plagioclase, and pyroxene that is overprinted by hornblende (Plate 22). Garnet-absent zones consisting of very fine-grained, recrystallized pyroxene, which is overprinted by hornblende, separate the zones of abundant garnet.

In rare occurrences, the rocks contain relict igneous textures and minerals, which are variably overprinted by amphibolite-facies coronitic textures. The coronas are similar to those at Ossokmanuan Lake, the main difference being the total absence of olivine.

Lac Joseph Area

At Lac Joseph, the Shabogamo Gabbro is generally massive, and has a relict igneous intergranular texture, or partially pseudomorphed igneous texture. Cumulate-layered rocks are relatively common, and there are only local occurrences of foliated and mylonitic gabbro in which the igneous textures have been obliterated by recrystallization and growth of amphibolite-facies minerals.

The unit consists mainly of medium- to coarse-grained olivine–orthopyroxene gabbro containing 1- to 2-cm-long plagioclase laths that are variably pseudomorphed by fine-grained, granular plagioclase. The rocks at Lac Joseph are coarser grained, and generally more leucocratic than those at Ossokmanuan Lake. Fine- to medium-grained, intercumulus olivine and clinopyroxene have a variety of single and multiple corona structures that separate them from plagioclase. The coronas are identical to those at Ossokmanuan Lake with the exception of some complex garnet coronas that armour clinopyroxene (Plate 23). The garnet coronas have two textural zones consisting of an inner zone of garnet and abundant clinopyroxene inclusions, and an outer zone of inclusion-free garnet. The rocks also contain biotite and garnet coronas around ilmenite.

Rocks near the contact with the overlying Lac Joseph terrane, having a strong foliation, are also the most pervasively overprinted by amphibolite-facies metamorphism. These rocks are converted to foliated, fine- to medium-grained amphibolites containing hornblende, biotite and plagioclase, or hornblende, clinopyroxene, garnet, biotite and plagioclase. Hornblende, garnet and clinopyroxene occur as separate phases that, on the basis of the granoblastic textures, appear to be in equilibrium.

Plate 23. *Complex garnet (grt) corona consisting of alternating inclusion-rich zones (dusty appearance) and inclusion-free zones that armours orthopyroxene (opx) and olivine (olv). Photo DJ-90-2302.*

CHEMISTRY OF MAFIC INTRUSIVE ROCKS

GEOCHEMICAL DATA

The objectives of this section are to: 1) present the chemistry of Ossok Mountain intrusive suite and Shabogamo Gabbro, including major-, trace-, and rare-earth-element data, 2) make some quantitative comparisons of the data, and 3) speculate on the tectonic significance of these mafic intrusions based on the chemical data. Table 3 is a list of chemical data for the Ossok Mountain intrusive suite and Shabogamo Gabbro samples analyzed, including previously published data for the Shabogamo Gabbro and Michael Gabbro from Gower *et al.* (1991a). Appendix 2 is a complete list of chemical data. Sample locations are shown in Figure 12 and on Map 93-54.

A comparison of the major-element data in Table 3 shows that there are no statistical differences between the two suites. There is a suggestion from the data, however, that the Shabogamo Gabbro is slightly more alkaline than the Ossok Mountain intrusive suite as indicated to some extent on Figure 13. Because of the similarity in major-element compositions, attempts to discriminate between the suites based on comparisons of the less mobile components are equivocal, although Figures 14 and 15 demonstrate that, in general, the Ossok Mountain intrusive suite has a wider compositional variation relative to the Shabogamo Gabbro. The data indicate that the Shabogamo Gabbro contains higher P_2O_5 than the Ossok Mountain intrusive suite.

The data from Figures 13 and 16 indicate that both suites have a tholeiitic, subalkaline character. Both diagrams also illustrate the relative uniform composition of the Shabogamo Gabbro, and give an indication of compositional trends in the Ossok Mountain intrusive suite that may imply more extensive fractionation relative to the Shabogamo Gabbro. It could be argued that the alkali components were mobile during metamorphism, but plots of components that may have been mobile versus less mobile components (Figure 17) show systematic mutual variations suggesting that compositions of alkali components were not significantly altered by metamorphism.

Both suites have statistically similar trace-element compositions. Figures 18, 19 and 20 highlight some differences in chemistry, and also display the chemical variability of the Ossok Mountain intrusive suite relative to the Shabogamo Gabbro. The data also suggest that the Ossok Mountain rocks are somewhat more abundant in Zn, Ni and Cr, whereas the Shabogamo Gabbro contains more Pb. Classification of both suites based on combinations of trace elements and SiO_2 content (Figures 21 and 22), following the scheme of Winchester and Floyd (1977), are consistent with the interpretation that both suites are mainly subalkaline with some variation toward alkali basalt.

In Figures 23 and 24 the majority of samples of Shabogamo Gabbro define tight clusters within the fields

Table 3A. Major-element chemistry of the Ossok Mountain intrusive suite and the Shabogamo Gabbro

UNIT	SiO_2	Al_2O_3	TOTAL Fe	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI
Ossok mean	49.78	17.98	9.71	2.83	6.19	8.89	9.35	2.45	0.62	0.70	0.15	0.14	0.86
std. dev.	2.46	1.71	1.64	1.13	1.30	3.20	0.95	0.64	0.54	0.40	0.02	0.16	0.13
Shabogamo mean	49.09	17.77	11.34	2.64	7.83	7.20	8.90	2.85	1.27	1.37	0.16	0.30	0.97
std. dev.	2.01	2.28	2.38	0.81	1.68	3.02	1.06	0.57	1.06	0.76	0.04	0.16	0.15
SG *	49.18	16.83			11.37	7.99	8.45	2.81	1.04	1.76	0.17	0.40	
std. dev.	3.47	2.61			2.05	3.41	1.20	0.44	0.85	0.82	0.04	0.34	
MG *	47.55	16.92			13.05	7.61	8.55	2.83	0.99	1.91	0.18	0.41	
std. dev.	1.77	2.88			2.62	3.32	1.27	0.48	0.50	0.74	0.04	0.23	

* The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower *et al.* (1991a).

Table 3B. Trace- and rare earth-element chemistry of the Ossok Mountain intrusive suite and the Shabogamo Gabbro

Unit	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Gd 160	Tb	Dy	Ho	Er	Tm
Ossok mean	516	10	46	3	333	12.4	25.8	3.1	12.4	2.4	0.82	2.26	2.17	0.29	1.80	0.36	1.04	0.15
std. dev.	302	6	46	3	248	10.9	23.2	2.8	11.2	2.0	0.47	1.67	1.59	0.20	1.27	0.24	0.67	0.09
Shabogamo mean	323	22	122	6	461	19.0	42.0	5.2	21.3	4.5	1.46	4.65	4.52	0.68	4.09	0.83	2.38	0.34
std. dev.	64	10	60	3	195	9.0	20.0	2.5	9.8	2.1	0.48	2.16	2.13	0.32	1.97	0.40	1.16	0.18
SG *	317	33	153	8	428	15.4	35.7	4.5	21.0	4.6	1.6	5.0			4.6	1.6	2.7	
std. dev.	55	18	96	6	223	2.0	4.6	0.6	2.9	0.6	0.2	0.6			0.6	2.6	0.3	
MG *	343	32	157	10	466	21.2	47.4	5.8	26.1	5.3	1.8	5.5			4.8	1.0	2.8	
std. dev.	85	14	68	3	433	7.8	17.6	2.2	9.7	2.1	0.5	2.1			1.9	0.4	1.1	

* The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower *et al.* (1991a).

Table 3B. Continued

Unit	Yb	Lu	Hf	Ta	Th	Ga	V	Sc	Li	Be	Cu	Pb	Zn	Ni	Rb	Cr	Mo	Co
Ossok mean	1.02	0.16	1.28	0.12	0.64	27	197	32.1	14.7	1.2	59	36	59	192	15	202	4	39
std. dev.	0.63	0.09	1.19	0.12	1.10	5	61	4.9	8.1	0.1	32	51	44	182	12	124	0	10
Shabogamo mean	2.16	0.34	3.12	0.31	1.69	28	181	26.5	11.7	1.2	45	91	20	122	23	123	4	41
std. dev.	1.09	0.17	1.49	0.16	0.87	6	91	14.0	7.2	0.4	20	53	36	79	13	63	1	5
SG *	2.4	0.4			3.0	21.0	166.0				38	9	117	127	25	93		
std. dev.	0.3	0.0			3.0	2.9	61.0				17	6	60	104	24	62		
MG *	2.5	0.4			4.0	21.0	203.0		10.00		44	1	125	107	25	142	4	
std. dev.	1.0	0.2			3.0	6.0	74.0		4.00		50	1	29	80	13	175	1	

* The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower *et al.* (1991a).

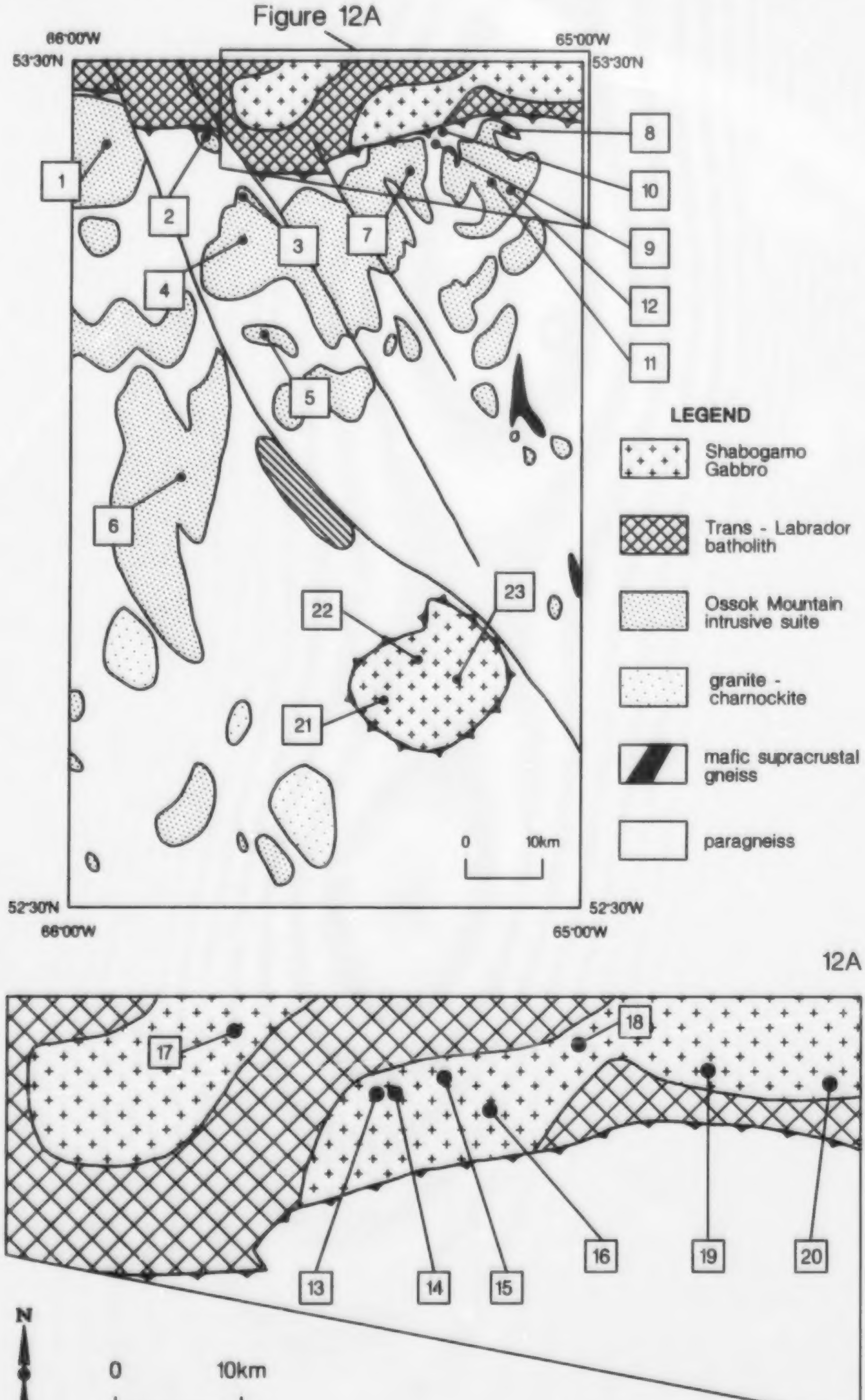


Figure 12. *Geochemical sample locations. Figure 12A (inset) is a detailed map showing sample locations in the Ossokmanuan Lake area.*

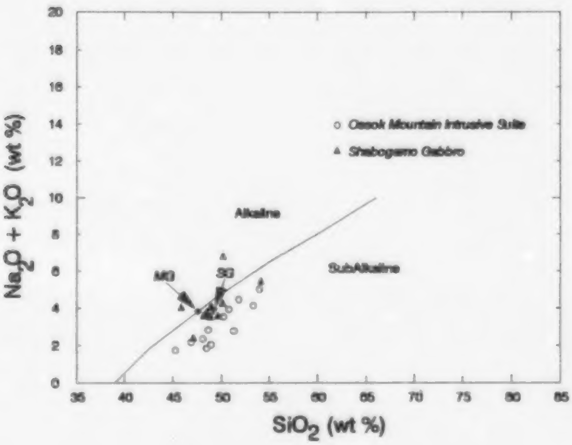


Figure 13. *Na_2O + K_2O vs SiO_2 for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

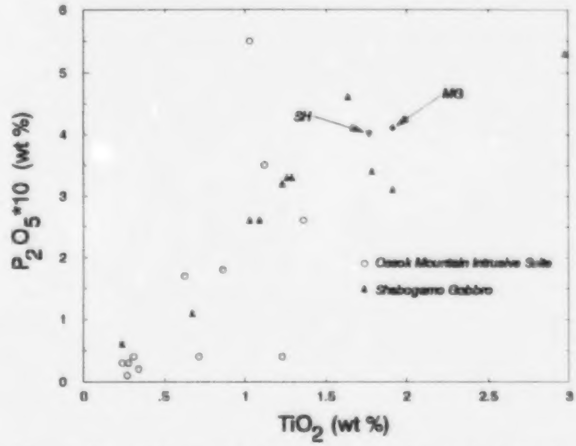


Figure 15. *P_2O_5 vs TiO_2 for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

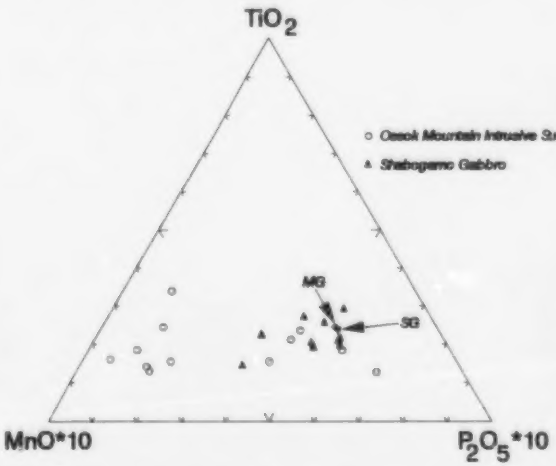


Figure 14. *MnO–TiO_2–P_2O_5 diagram for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

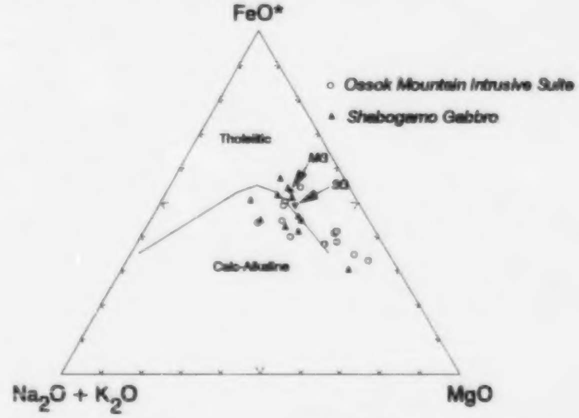


Figure 16. *Na_2O + K_2O–FeO–MgO for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. Fields after Irving and Baragar (1971). The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

defined by within-plate basalts, consistent with the conclusions made by Gower *et al.* (1991a). In contrast, the Ossok Mountain samples form a relative widespread grouping in Figure 23, with six of the samples falling within the within-plate basalt field, and the remainder mainly within the low-K tholeiite field. Figure 24 also shows the chemical variability of the Ossok Mountain samples, although there is a suggestion from the diagram that the data form two groups, one falling within the fields defined by within-plate tholeiite and the other in the volcanic-arc basalt field. The significance of these two groups will be discussed later.

Shabogamo Gabbro REE profiles (Figure 25) show a pattern of relative enrichment of light-REE's, variable Eu anomalies and flat heavy-REE profiles, typical of REE profiles for mafic cumulate rocks. The four samples that have the lowest REE contents have positive Eu anomalies, whereas the samples that have the highest REE contents have negative or flat Eu anomalies. Gower *et al.* (1991a) have reported similar REE profiles for both the Shabogamo and Michael gabbros, and have concluded on the basis of the REE data that the rocks are typical continental tholeiites. In particular, REE profiles presented in this paper for the Shabogamo Gabbro, share some similar characteristics with Gower *et al.*'s (1991a) Michael Gabbro REE profiles, which they interpret as indicative of derivation from a slightly light-REE enriched source that had a flat heavy-REE profile and a slightly positive Eu anomaly. Variable fractionation of plagioclase from the

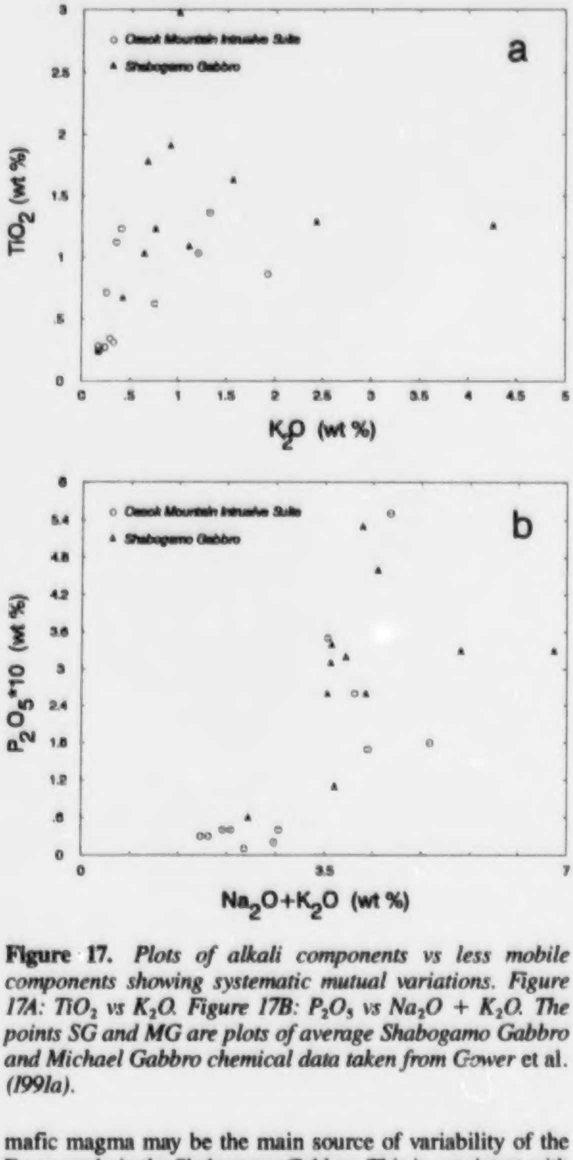


Figure 17. *Plots of alkali components vs less mobile components showing systematic mutual variations. Figure 17A: TiO_2 vs K_2O. Figure 17B: P_2O_5 vs $Na_2O + K_2O$. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

mafic magma may be the main source of variability of the Eu anomaly in the Shabogamo Gabbro. This is consistent with the observation that the largest positive Eu anomaly is from a leucotroctolite containing cumulus plagioclase.

REE profiles for Ossok Mountain intrusive suite rocks (Figure 26) are somewhat similar in form to the Shabogamo Gabbro profiles, although the ratio of light-REE to heavy-REE is generally smaller in the Shabogamo Gabbro than in the Ossok Mountain Suite. Whereas the Shabogamo Gabbro data form a relatively tight cluster of parallel profiles, the Ossok Mountain data lie in two sets of subparallel profiles. One set consists of relatively high REE contents, and shows enrichment of light-REE's, flat heavy-REE profiles, and variable Eu anomalies, both positive and negative. The other set has lower REE contents, relatively low light-REE to heavy-REE ratios, and positive Eu anomalies. The latter group of

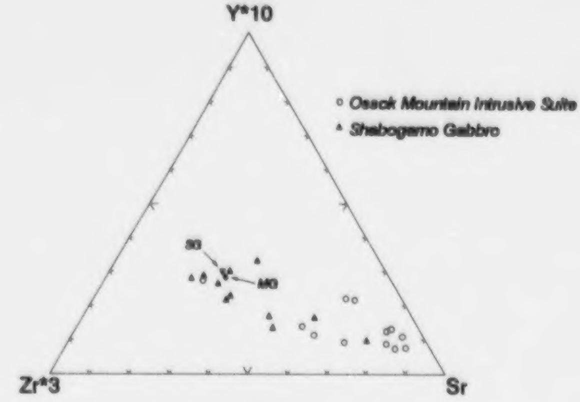


Figure 18. *Zr–Y–Sr diagram. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

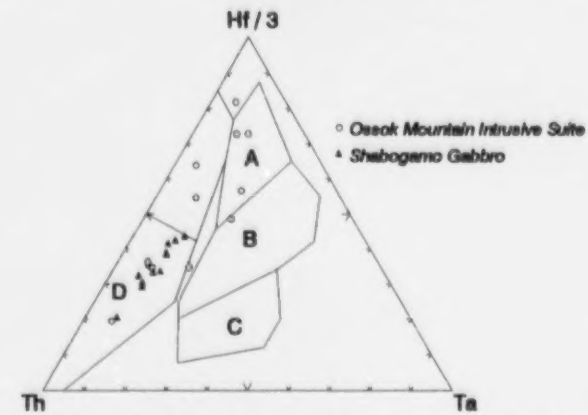


Figure 19. *Th–Hf–Ta diagram. A = N-type MORB; B = E-type MORB; C = alkaline within-plate basalt; and D = destructive-plate margin basalts (fields from Wood, 1980).*

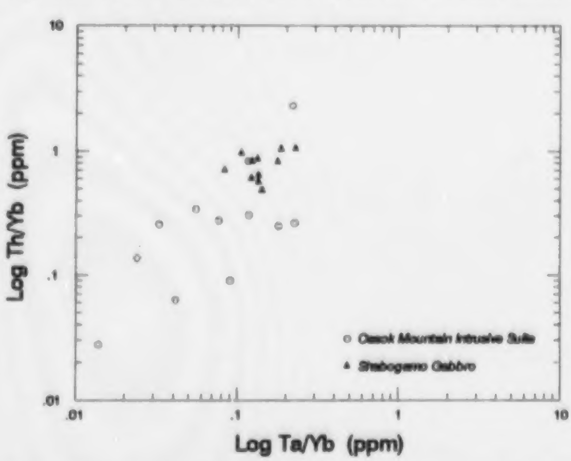


Figure 20. *Th/Yb vs Ta/Yb for the Ossok Mountain intrusive suite and the Shabogamo Gabbro.*

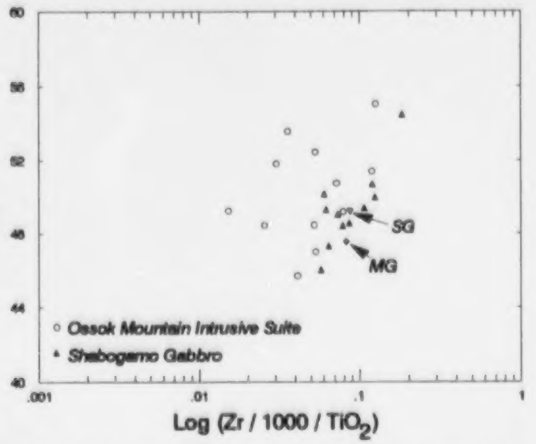


Figure 21. *SiO_2 vs Zr/TiO_2 for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

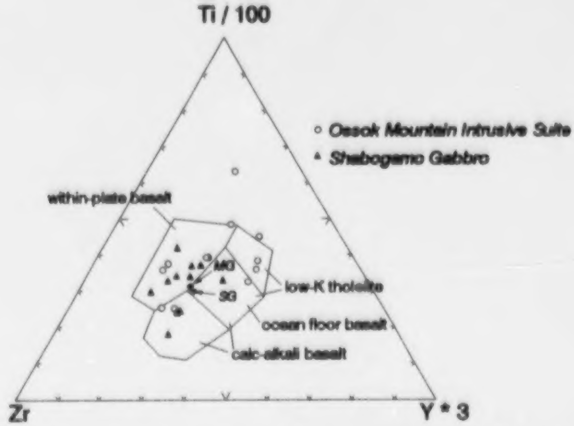


Figure 23. *Zr–Ti–Y diagram. Fields from Pearce and Cann (1973). The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

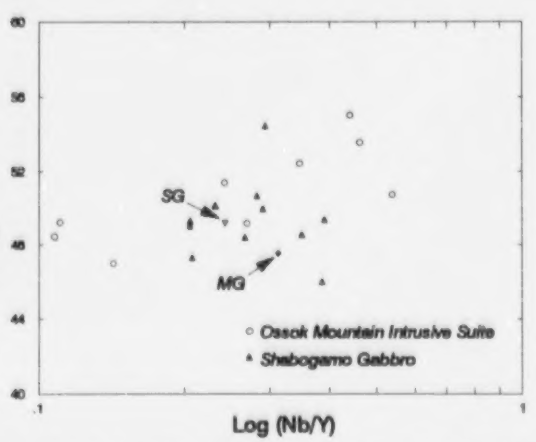


Figure 22. *SiO_2 vs Nb/Y for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

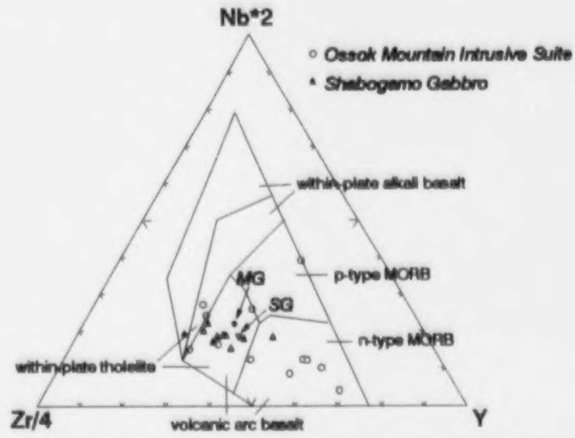


Figure 24. *Zr–Nb–Y diagram. Fields from Meschede (1986). The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

REE profiles corresponds to the six samples that fall within the volcanic-arc basalt field in Figure 23. The variability between the two sets of REE profiles for the Ossok Mountain samples suggests varied fractionation resulting in enrichment of light-REE's in the more fractionated rocks. The wide variation in REE contents and higher light-REE to heavy-REE ratios suggest that Ossok Mountain intrusive suite rocks are generally more fractionated than the Shabogamo Gabbro.

The extended REE profiles (Figures 27 and 28) for both suites have approximately the same general shape, although there is generally greater variability in the Ossok Mountain profiles compared to the tightly grouped Shabogamo Gabbro profiles. One difference between the profiles is the positive correlation between 1) Sr and Eu and 2) Sr and Nb anomalies in the Ossok Mountain intrusive suite (Figures 29 and 30) compared to the relatively constant Sr contents in the Shabogamo Gabbro.

INTERPRETATION

The chemistry of the Shabogamo Gabbro is consistent with that of a tholeiitic basalt, possibly from a within-plate environment. This inference is in agreement with Gower *et al.'s* (1991a) conclusions based on their much larger dataset.

The Ossok Mountain intrusive suite chemistry represents a geographically and numerically restricted dataset, although

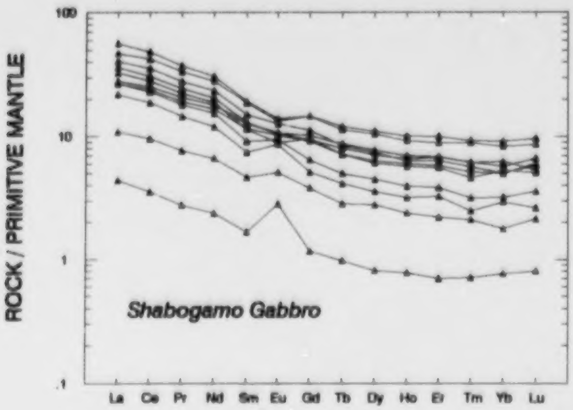


Figure 25. *Rare-earth-element profiles for the Shabogamo Gabbro.*

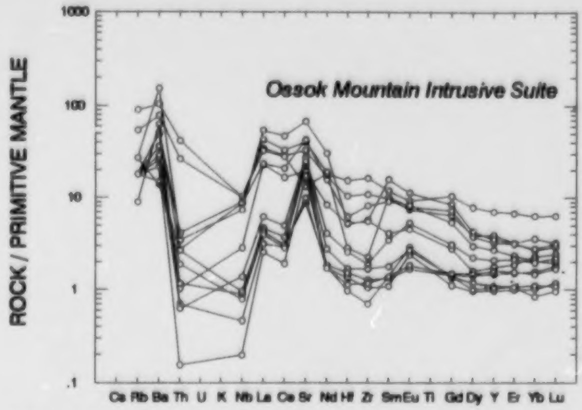


Figure 28. *Extended rare-earth-element profiles for the Ossok Mountain intrusive suite.*

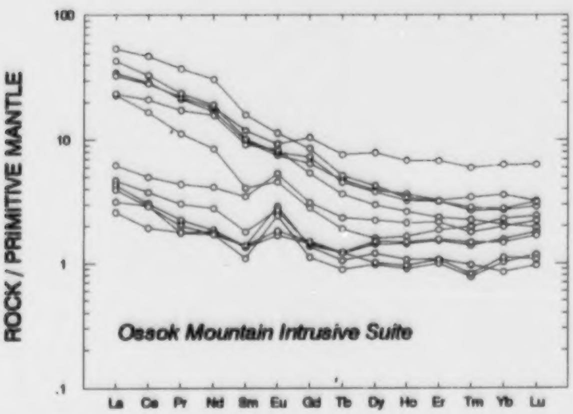


Figure 26. *Rare-earth-element profiles for the Ossok Mountain intrusive suite.*

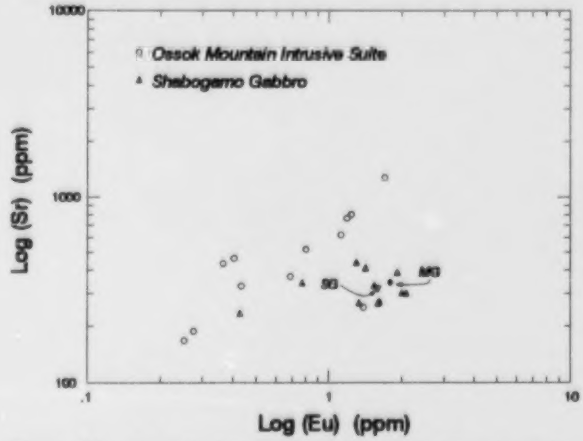


Figure 29. *Sr vs Eu for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

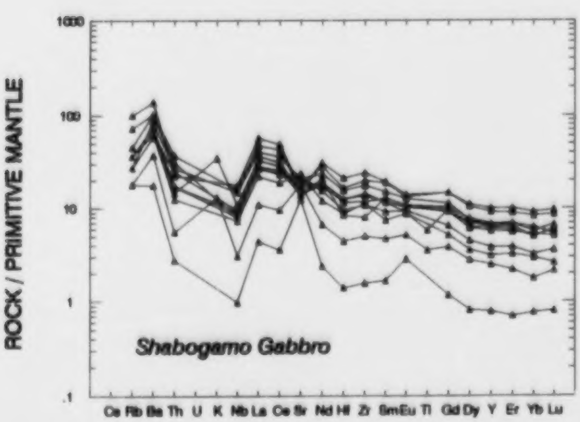


Figure 27. *Extended rare-earth-element profiles for the Shabogamo Gabbro.*

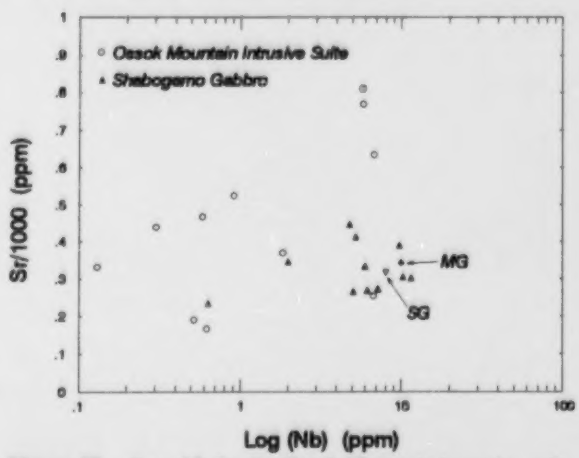


Figure 30. *Sr vs Nb for the Ossok Mountain intrusive suite and the Shabogamo Gabbro. The points SG and MG are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower* et al. *(1991a).*

several conclusions are suggested by the data. The data indicates, in general, that 1) the Ossok Mountain intrusive suite has a greater chemical variability and shows evidence of more variable degrees of fractionation compared to the Shabogamo Gabbro; 2) the major- and trace-element chemistry is consistent with subalkaline tholeiitic basalt; 3) some parts of the Ossok Mountain suite may be intrusive equivalents of volcanic-arc basalt; and 4) REE profiles suggest that the least fractionated Ossok Mountain rocks, corresponding to those that have a comparable chemistry to volcanic-arc basalt, may be the source for the more highly fractionated parts of the Ossok Mountain intrusive suite. These conclusions suggest that the Ossok Mountain intrusive suite may be genetically related to magmatism in a Labradorian arc whose granitic units make up the Trans-Labrador batholith.

STRUCTURAL GEOLOGY

The objectives of this section are to describe the definition, attitude, kinematic significance, and age relations of structures. These relations, along with results from the metamorphic and geochronological studies, will be used to construct a structural, metamorphic and intrusive chronology that will be the basis for the tectonic model developed and discussed later (Tectonic Evolution section, page 43).

STRUCTURES IN THE LAC JOSEPH TERRANE

The oldest structure in the Lac Joseph terrane is a foliation in paragneiss defined by biotite and the first metamorphic leucosome, and referred to as S_1 (Plate 24). S_1 occurs only rarely as it is mainly obliterated by a second foliation, S_2, which is the principal foliation in paragneiss in the Lac Joseph terrane. S_2 is defined by biotite, alignment of sillimanite and the transposed first leucosome, and has variably overprinted the second leucosome. A schematic representation of the S_1/S_2 relations is shown in Figure 31. S_2 is interpreted to be a Labradorian foliation because high-grade Labradorian minerals grow along S_2 in paragneiss, and that both metamorphic leucosomes have been dated by Connelly *et al.* (1990) and Connelly and Heaman (1993) as Labradorian.

Plate 24. *Photograph of migmatitic paragneiss showing the relations between S_1 and S_2. Photo DJ-90-2255.*

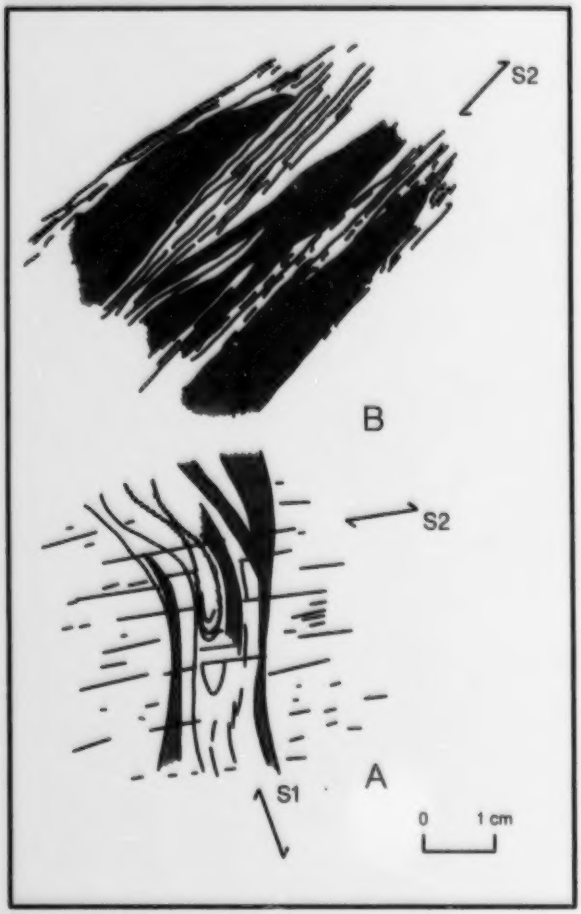


Figure 31. *Sketch showing the S_1/S_2 relations in paragneiss in the southwestern part of the study area (A), and in the central and northern parts of the study area (B).*

The attitude of S_2 in paragneiss is varied throughout the Lac Joseph terrane (Figure 32), and the regional variation is illustrated in Figure 33. The data show a swing in S_2 from dominantly north-northeast- to north-northwest-striking, from the central part of the Lac Joseph terrane (domain 3) toward the northern margin of the terrane (domain 1). This is also reflected in a change in attitude of mineral elongation lineations in paragneiss (Figure 34). The age and significance of this attitude variation are discussed in a subsequent section.

The oldest structures in the Ossok Mountain intrusive suite are local occurrences of relict, cumulate layering and

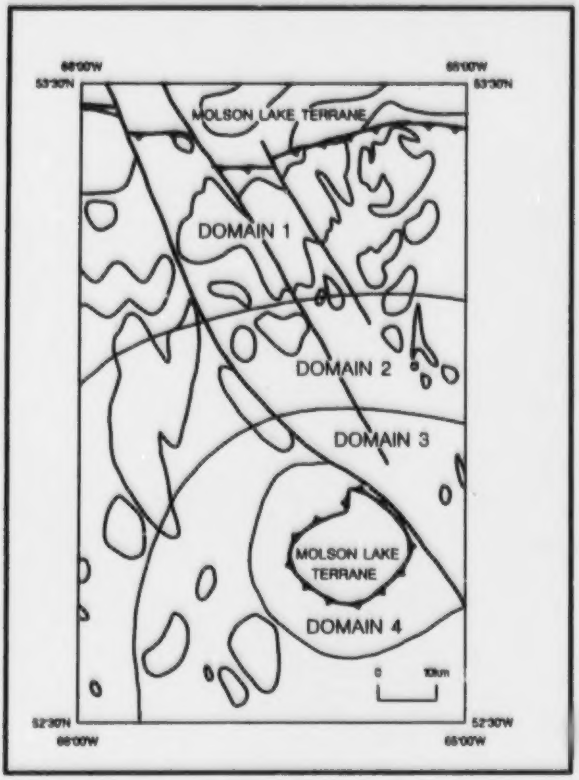


Figure 32. *Structural domains in the Lac Joseph terrane.*

igneous lamination defined by alignment of igneous plagioclase laths. These structures may have been common, but were chiefly obliterated during recrystallization that accompanied Labradorian metamorphism. The presence of metamorphic orthopyroxene in recrystallized rocks demonstrates that recrystallization was concomitant with granulite-facies conditions. The high-grade metamorphism and attendant formation of the principal foliation in the Ossok Mountain rocks, which is defined by alignment of the metamorphic minerals, is Labradorian and interpreted to be the same age as S_2 in the paragneiss. This correlation is consistent with the observation that the principal foliation in both units is defined by the peak Labradorian metamorphic minerals, and that they have similar attitudes.

There are occurrences of recrystallized, high-grade Ossok Mountain dykes that are discordant to the S_2 foliation in the paragneiss, but these are a very minor part of the Ossok Mountain intrusive suite. These dykes demonstrate that mafic magmatism locally outlasted the main phase(s) of Labradorian deformation.

Similar to the regional variation of S_2 in the paragneiss, the attitude of the principal foliation (S_2) in the Ossok Mountain intrusive suite rocks is also varied in the Lac Joseph terrane. From domain 2 to domain 1, the attitude varies from dominantly north-trending to north-northwest-trending (Figure 35). There are very few occurrences of Ossok Mountain intrusive suite rocks in domain 3, hence the south-to-north variation from domains 3 to 1 could not be examined.

The variation in attitude of S_2 in the Lac Joseph terrane, in both the paragneiss and the Ossok Mountain intrusive suite rocks, corresponds to the change from an area of dominantly northeast- to north-northeast-trending F_2 folds to an area of dominantly north-northwest-trending F_3 folds. Both F_2 and F_3 are defined by folds of the S_2 foliation and the metamorphic leucosomes. Map-scale F_3 folds are defined by the folded contacts between the paragneiss and the Ossok Mountain intrusive suite rocks. Locally, minor F_3 folds are observed to overprint F_2 folds, generating Type III (Ramsay, 1967) superposed fold patterns. In paragneiss, minor F_3 fold axes are locally defined by elongate sillimanite which is inferred to be Labradorian in age. F_3 folds have mainly south-southeast-trending, shallow- to moderate-plunging fold axes (Figure 36). The F_3 fold axes are parallel to the regional, mineral elongation lineation which is defined by high-grade minerals that are inferred to be Labradorian.

Age of F_3 Folds and Regional Variation in S_2

The age of the F_3 folds and the regional variation from dominantly north-northeast-trending structures to north-northwest-trending structures is equivocal, and there is conflicting evidence that supports both a Labradorian and Grenvillian age.

The evidence that supports a Labradorian age for F_3 and the regional variation in attitude of S_2 includes:

1. S_2 is defined by the high-grade, Labradorian metamorphic assemblage in domains 3, 2 and 1. There is no evidence of a zone of progressive, south-to-north overprinting by Grenvillian-age metamorphism, or any other post-Labradorian metamorphism, that would correspond to the zone of structural transition from north-northeast- to north-northwest-trending structures. This point is significant when one considers that the Grenvillian metamorphic grade in the contiguous Molson Lake terrane reached amphibolite-facies conditions with moderate to high pressures (e.g., Connelly *et al.*, 1989; Connelly, 1991), and yet the Lac Joseph terrane, and domain 1 in particular, shows no significant signs of a Grenvillian metamorphic overprint.

2. Minor F_3 folds both deform the S_2 foliation that contains Labradorian sillimanite, and locally have axes which are defined by Labradorian sillimanite. F_3 fold axes are approximately collinear with the mineral elongation lineation in domain 1 that is defined by inferred Labradorian minerals. These relationships suggest that high-grade Labradorian conditions, and growth of sillimanite, persisted during F_2 and F_3 folding.

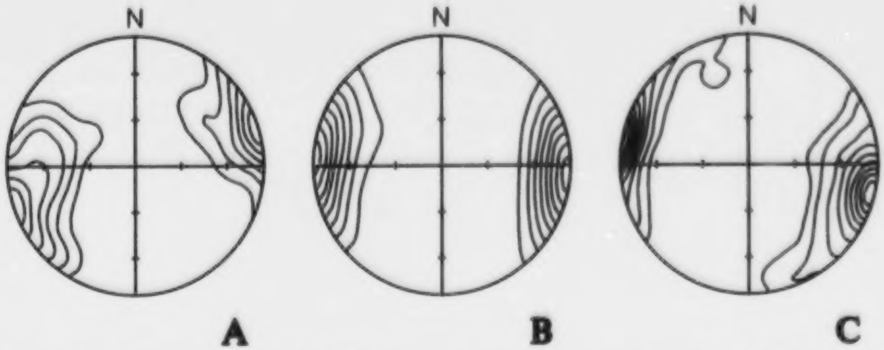


Figure 33. *Contoured, lower hemisphere, equal-area projections of poles to S_2 in paragneiss in the Lac Joseph terrane. Contours are in increments of 2σ. A–poles to S_2 in domain 1. $n=141$, $\sigma=1.41$; B–poles to S_2 in domain 2. $n=50$, $\sigma=1.27$; and C–poles to S_2 in domain 3. $n=154$, $\sigma=1.42$.*

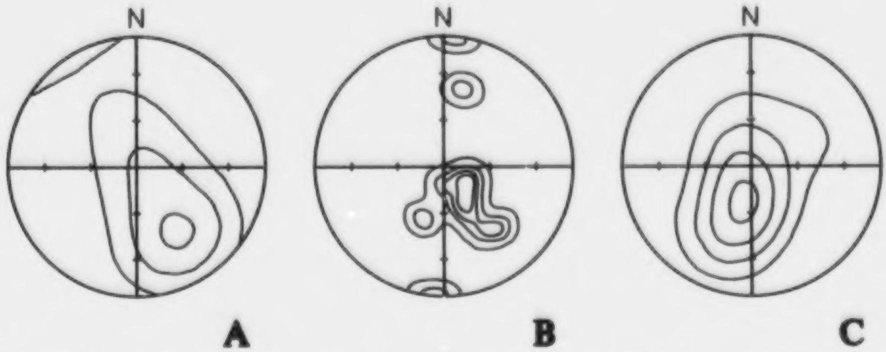


Figure 34. *Contoured, lower hemisphere, equal-area projections of mineral elongation lineations in paragneiss. A–domain 1. $n=11$, $\sigma=0.83$, peak=146/40; B–domain 2. $n=11$, $\sigma=0.83$, peak=149/64; and C–domain 3. $n=23$, $\sigma=1.08$, peak=191/67.*

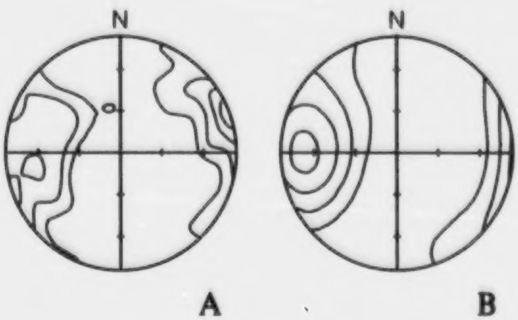


Figure 35. *Contoured, lower hemisphere, equal-area projections of poles to S_2 in the Ossok Mountain intrusive suite. Contours are in increments of 2σ. A–poles to S_2 in domain 1. $n=154$, $\sigma=1.42$; and B–poles to S_2 in domain 2. $n=23$, $\sigma=1.08$.*

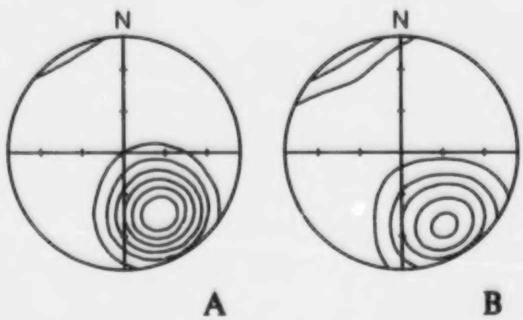


Figure 36. *Contoured, lower hemisphere, equal-area projections of F_3 fold axes in paragneiss (A) and the Ossok Mountain intrusive suite (B) in domain 1. A–$n=33$, $\sigma=1.18$; and B–$n=19$, $\sigma=1.02$*

3. If the north-northwest-striking attitude of S_2 in domain 1 was a product of Grenvillian strain, then one might expect there to be a Grenvillian foliation having a similar orientation in contiguous Molson Lake terrane rocks at Ossokmanuan Lake. However, presumed Grenvillian foliations in rocks at Ossokmanuan Lake, and farther north in Lower Proterozoic supracrustal rocks, are mainly northeast- to east-northeast-striking, and are clearly discordant to the structural trend of S_2 in the Lac Joseph terrane. These observations support a Labradorian age for F_3 and suggest that F_2 and F_3 are the result of a single, continuous and progressive Labradorian deformation event.

There is a casual correspondence between the change from domain 3 to domain 1 structures with an increase in Labradorian paleodepth in the Lac Joseph terrane. The increase in paleodepth is marked by the appearance of kyanite in paragneiss in domain 1. The kyanite grows along S_2, thus it is inferred to be a Labradorian metamorphic mineral. This correspondence may suggest that Labradorian structural attitude changes with depth in the Lac Joseph terrane. The presence of kyanite along the northern margin of the terrane also suggests that the Lac Joseph terrane represents an oblique depth-section through Labradorian crust.

Alternatively, there are arguments that favour a Grenvillian age for F_3.

1. North-northwest-trending folds have been recognized by Rivers (1985b,c), Nunn and Christopher (1983), Nunn *et al.* (1984), Wardle (1985), Rivers and Chown (1986) and Connelly and Scowen (1987) in the Gagnon, Molson Lake and Churchill Falls terranes. These folds, inferred to be Grenvillian, have approximately the same attitude as F_3 folds in the Lac Joseph terrane.

2. Grenvillian foliation in the Lac Opocopa area (southwestern Molson Lake terrane) and in the Wabush Lake area (Gagnon terrane) is northwest-striking (see Rivers, 1985a,c). This attitude is consistent with the north-northwest-trending Grenvillian folds in these areas, and is compatible with an east-northeast–west-southwest Grenvillian contractional deformation that could also have been responsible for F_3 folding and passive reorientation of S_2 in the Lac Joseph terrane.

3. Wardle (1985) has speculated that the F_3 folds in the Lac Joseph terrane may be related to a Grenvillian thrusting event that carried the Lac Joseph terrane over the Molson Lake and Churchill Falls terranes. Following models for folding in nappes (see Mattauer, 1975; Mattauer *et al.*, 1983), Wardle (1985) has proposed that the F_3 folds might be akin to sheath folds and related to attenuation of the thrust sheet in the direction of tectonic transport.

The relations between structures and high-grade metamorphic minerals is the most compelling evidence to suggest that F_3 folds in the Lac Joseph terrane are Labradorian. The discordance in orientation between structures in the Lac Joseph terrane and structures in contiguous Molson Lake terrane rocks at Ossokmanuan Lake, which are known to be Grenvillian, is consistent with a Labradorian age for F_3. Equally, it could be argued that the structures in domain 1 are correlative with northwest-trending Grenvillian structures in the southwestern parts of the Molson Lake and Gagnon terranes. If the structures in domain 1 are Grenvillian, then F_3 folding and reorientation of S_2 occurred without Grenvillian retrogression or growth of new minerals.

Alternatively, the interpretation that the high-grade minerals in domain 1 are Labradorian may be erroneous. Could the metamorphic minerals in domain 1 be Grenvillian phases which mimicked Labradorian structure? The age of F_3 and the regional variation of S_2 is unresolved and remains an outstanding problem.

A Tectonic Window Through the Lac Joseph Terrane

In the Lac Joseph area, the Shabogamo Gabbro and a lesser amount of the granitoid gneiss, which are correlated with the Trans-Labrador batholith, are separated from the surrounding Labradorian gneisses by a Grenvillian high-strain zone that is inferred to be the main, Lac Joseph terrane–Molson Lake terrane boundary (JMBZ). On this basis, Connelly (1988) has concluded that the rocks at Lac Joseph, which have Molson Lake terrane affinity, are exposed in a structural window through the Lac Joseph terrane.

The area around the tectonic window contains abundant occurrences of muscovite-bearing, retrogressed paragneiss, and amphibolite-facies (retrogressed from granulite facies) mafic supracrustal gneiss. The retrogression is patchy on the map scale, but it is generally most pervasive in areas within several hundred metres of the margin of the window. The spatial relation between the area of retrogression and the margin of the tectonic window suggests that the retrogression is also a Grenvillian feature.

Kyanite also occurs sporadically around the margin of the window. The age of the kyanite is equivocal. If the kyanite is Labradorian, its presence might support the model of increasing Labradorian paleodepth toward the structural base of the Lac Joseph terrane. Alternatively, the kyanite could be younger and related to Grenvillian metamorphism of the Lac Joseph terrane in areas contiguous with the underlying terranes.

Approximately coincident with the area of Grenvillian retrogression around the window is an area (domain 4) in which the attitude of the principal foliation in paragneiss is variable, and clearly distinct from S_2 attitudes in domains 2 and 3. The foliation in the paragneiss in domain 4 is defined by both high-grade Labradorian minerals and the

metamorphic leucosomes, and by biotite and muscovite in retrogressed paragneiss. In mafic supracrustal gneiss, the foliation is defined by alignment of hornblende, biotite and plagioclase streaks. Figure 37 demonstrates that S_2 in domain 4 is approximately parallel to the margin of the window. This similarity in attitude, and the fact that the foliation is locally defined by amphibolite-facies minerals that are inferred to be Grenvillian, suggests that the attitude of the foliation in domain 4 is a Grenvillian feature. The occurrence of biotite and muscovite in retrogressed paragneiss, and hornblende, biotite and plagioclase in mafic supracrustal gneiss, which have grown along the foliation in domain 4, demonstrate that Grenvillian deformation of rocks near the structural base of the Lac Joseph terrane was concomitant with amphibolite-facies metamorphism.

Figure 37. *Contoured, lower hemisphere, equal-area projections of poles to foliation and gneissosity in paragneiss in domain 4. n=58, σ=1.3. Planar fabrics in paragneiss dip steeply to east, south and west, away from the eastern, southern and western margins of the window.*

The relations between foliation and metamorphic minerals in domain 4 suggest that the Labradorian S_2 was passively re-oriented during Grenvillian deformation of the Lac Joseph terrane, which was responsible for the formation of a structural culmination that became the tectonic window itself. The patchy retrogression in domain 4 is probably a function of the availability of water during Grenvillian deformation. Grenvillian, amphibolite-facies minerals appear to have mimicked the Labradorian S_2 in retrogressed rocks.

The overall shape of the Lac Joseph terrane is also inferred to be the consequence of the same Grenvillian folding that produced the tectonic window and the pattern of foliation in domain 4. The Lac Joseph terrane is approximately spoon-shaped (Figure 38), and is the result of superposed, open folds that trend approximately 060° and 345°. The tectonic window occurs in the core of a structural culmination where two anticlines are superposed. The age of these folds is constrained to be younger than the JMBZ.

On a smaller scale, there are a few occurrences of rocks in the Lac Joseph terrane, in all structural domains, that have a weak, east-northeast-striking foliation that overprints the Labradorian S_2 foliation. The east-northeast-striking foliation is locally axial planar to open, steeply-plunging folds of the Labradorian gneissosity and foliation. These structures are

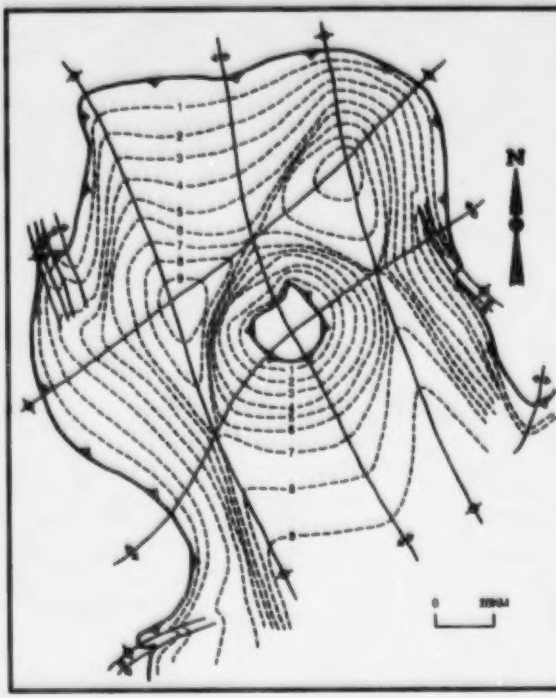


Figure 38. *Structural thickness map of the Lac Joseph terrane showing estimated depth contours to the JMBZ. Contour interval is 1 km. Also shown are traces of axial planes of superimposed Grenvillian anticlines and synclines that fold the Lac Joseph terrane. The northwest-striking faults have been removed.*

inferred to be Grenvillian and may be related to the map-scale structures described in the preceding paragraph. There were no occurrences of penetrative, 345°-trending structures in the Lac Joseph terrane that could be related to the Grenvillian folding.

Connelly (1991) also reports occurrences of foliated, Grenvillian pegmatites in the Lac Joseph terrane, providing further evidence that the Lac Joseph terrane was at least locally affected by Grenvillian strain at the outcrop scale.

STRUCTURES IN THE MOLSON LAKE TERRANE

In contrast to the Lac Joseph terrane, metamorphism and the attendant formation of a regional, penetrative foliation occurred in Molson Lake terrane rocks during the Grenvillian Orogeny (Connelly and Nunn, 1988, Connelly, 1991); in the study area, Grenvillian metamorphism reached the middle amphibolite-facies (see Rivers and Mengel, 1988).

Trans-Labrador batholith rocks and Shabogamo Gabbro are variably foliated. In the Trans-Labrador batholith rocks, the foliation is defined by biotite, and locally by recrystallized

quartzofeldspathic aggregates or muscovite. Occurrences of massive, isotropic- and megacrystic-textured Trans-Labrador batholith rocks are common. Similarly, rocks of the Shabogamo Gabbro are commonly massive and have relict cumulate layering and mineral laminations. Less commonly, the Shabogamo Gabbro rocks are recrystallized and foliated, and contain a foliation which is defined by recrystallized, amphibolite-facies mineral aggregates, including hornblende and plagioclase. The foliation in both units is dominantly northeast- to east-northeast-striking (Figures 39 and 40).

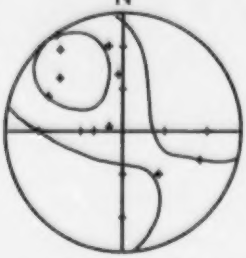


Figure 39. *Contoured, lower hemisphere, equal-area projections of poles to Grenvillian foliation and gneissosity in Trans-Labrador batholith rocks in the Molson Lake terrane. n=10, σ=0.79.*

Figure 40. *Contoured, lower hemisphere, equal-area projections of poles to Grenvillian foliation and gneissosity in Shabogamo Gabbro in the Molson Lake terrane. n=31, σ=1.16.*

STRUCTURE OF THE LAC JOSEPH TERRANE–MOLSON LAKE TERRANE BOUNDARY ZONE (JMBZ)

The JMBZ is poorly exposed, and its position is mainly inferred from magnetic anomaly data. In the northeast corner of the study area, where it is best exposed, rocks in both terranes are variably strained from protomylonite to ultramylonite. Rocks in both terranes are similarly strained around the margin of the tectonic window at Lac Joseph. On the basis of these observations, the boundary is inferred to be a ductile high-strain zone. The high strain persists, although it is heterogeneously distributed, for several kilometres on both sides of the boundary, although occurrences of ductile high-strain structures are apparently more common in the Molson Lake terrane than in the Lac Joseph terrane.

Structural and Metamorphic Relations in the Northeastern Part of the Study Area

In the northeastern part of the study area, highly strained rocks in the JMBZ are dominantly east-northeast-striking and dip moderately to the south-southeast (Figure 41). Mineral elongation lineations in high-strain zones are oriented down the dip, or are slightly oblique to the dip direction.

Highly strained paragneiss occurs within the JMBZ (Plate 25), in the Lac Joseph terrane proper, and also in high-strain zones in the area between the main boundary and Ossokmanuan Lake. The occurrences of highly strained paragneiss, north of the main terrane boundary, are inferred to be the result of tectonic interlayering of Lac Joseph terrane and Molson Lake terrane rocks. The paragneiss is dominantly fine-grained containing biotite, and commonly garnet. Both biotite and garnet are highly strained but they are not retrogressed. Locally, the rocks contain deformed, relict kyanite porphyroblasts that are overgrown by a fine-grained aggregate of biotite and muscovite. Muscovite also occurs as a fine-grained phase throughout the rocks, and locally forms fine-grained, mesh-like pseudomorphs after K-feldspar, although relict, medium- to coarse-grained K-feldspar porphyroclasts are common. Sillimanite occurs locally as fine-grained needles that appear to grow along the high-strain structures. These relations suggest that in paragneiss, the assemblage biotite + muscovite + garnet ± sillimanite, was stable during at least the latest part of the high-strain event along the terrane boundary. Ossok Mountain intrusive suite rocks may also occur with paragneiss in tectonic slices, north of the main terrane boundary, although it would be difficult to distinguish these highly strained and retrogressed rocks from similarly strained Shabogamo Gabbro.

Highly strained mafic intrusive rocks that occur along the JMBZ, including Shabogamo Gabbro and possibly Ossok Mountain intrusive suite rocks, are variably retrogressed. The most extensively retrogressed rocks are converted to fine-grained, strongly foliated amphibolites containing hornblende and plagioclase, and local biotite and minor amounts of quartz (Plate 26). Locally, the mafic rocks contain relics of igneous pyroxenes that occur in fine-grained, recrystallized, lenticular aggregates that define the high-strain structures. Pyroxenes are variably overgrown and replaced by hornblende. There are no occurrences of relict igneous olivine in any of the highly strained mafic rocks. The fact that hornblende grows along the high-strain fabrics demonstrates that high strain was attendant with amphibolite-facies metamorphism, and is consistent with observations from the paragneiss.

North of the main terrane boundary, high-strain zones in the Shabogamo Gabbro are common. These have a similar orientation as the main terrane boundary, and on this basis they are inferred to be the same age. The most highly strained

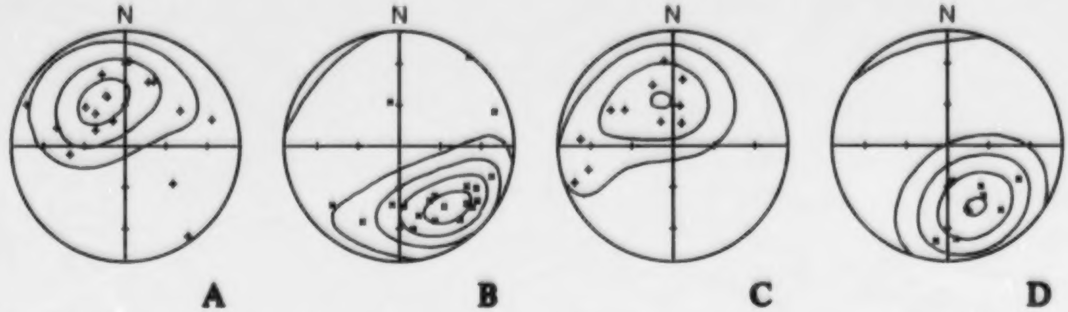


Figure 41. *Contoured, lower hemisphere, equal-area projections of poles to mylonitic fabrics and mineral elongation lineations in JMBZ high-strain zones. A–JMBZ high-strain zones in Trans-Labrador batholith rocks and Shabogamo Gabbro, Molson Lake terrane. n=17, σ=0.98; B–mineral elongation lineations in A. n=20, σ=1.03; C–JMBZ high-strain zones in the Lac Joseph terrane. n=12, σ=0.86; and D–mineral elongation lineations in C. n=9, σ=0.75.*

Plate 25. *Mylonitic paragneiss in the JMBZ. Photograph shows a view looking toward the west, perpendicular to the planar fabric (078°/42°). This outcrop contains a down-dip, mineral stretching lineation. Photo DJ-90-0276.*

Plate 26. *Highly strained Shabogamo Gabbro containing hornblende, clinopyroxene and garnet from Ossokmanuan Lake. Photograph shows the dip surface of the planar fabric (114°/52°), which contains a strong, southeast-plunging mineral stretching lineation. Photo DJ-90-2370.*

rocks in the Shabogamo Gabbro are protomylonitic metagabbros that have neither relict igneous textures nor coronitic structures that are both common in the lesser strained rocks in the area. Instead, these rocks have a fine-grained matrix of granoblastic plagioclase, and hornblende, garnet, biotite, apatite, opaque and local scapolite. The rocks also contain medium- to coarse-grained hornblende porphyroclasts that have relict clinopyroxene cores (Plate 27). These relations are consistent with amphibolite-facies assemblages in both highly strained paragneiss and mafic rocks along the JMBZ.

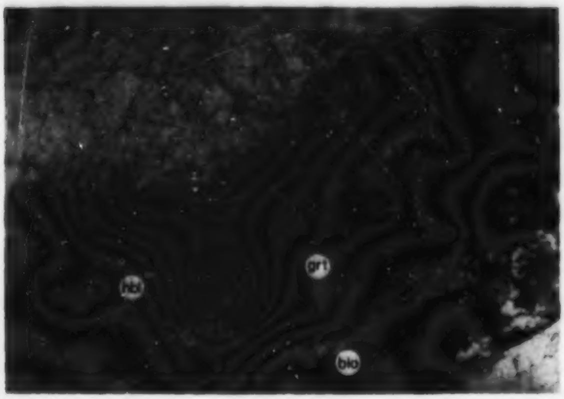


Plate 27. *Photomicrograph of highly strained, amphibolite-facies Shabogamo Gabbro from Ossokmanuan Lake. The gabbro is converted to a granoblastic rock containing plagioclase, hornblende (hbl), biotite (bio) and garnet (grt). The sample is from the outcrop shown in Plate 26.*

Highly strained granitoid rocks in the JMBZ are rare. Protomylonitic and mylonitic granitoid rocks, which appear to be derived from megacrystic Trans-Labrador batholith rocks, have microcline porphyroclasts which are surrounded by a fine-grained quartzofeldspathic matrix that includes minor amounts of biotite, garnet and hornblende.

Structural and Metamorphic Relations Around the Tectonic Window, Lac Joseph Area

Rocks are poorly exposed in the area around the margin of the tectonic window, and the majority of highly strained outcrops occur in the southwestern part of Lac Joseph. Highly strained paragneiss in this area is protomylonitic, containing abundant feldspar porphyroclasts (Plate 28). The rocks have a fine-grained, granoblastic (annealed) quartzofeldspathic matrix, and a foliation that is defined by biotite and quartzofeldspathic streaks. Rocks contain local, fine-grained garnet. Locally, the paragneiss contains abundant muscovite that overgrows the biotite foliation, demonstrating that the latest growth of muscovite was posttectonic with respect to the high strain.

Plate 28. *Protomylonitic paragneiss from the high-strain zone around the tectonic window, Lac Joseph. Photo DJ-90-2309.*

Highly strained mafic supracrustal rocks have a fine-grained, granoblastic texture defined by hornblende and plagioclase. Minor amounts of biotite, quartz and epidote are common. Rocks are straight-layered, and locally have a disrupted structure defined by lesser-strained gneissic boudins that are wrapped by a high-strain fabric. The fact that hornblende, plagioclase and biotite define the high-strain structures establishes that amphibolite-facies metamorphism was synchronous with the high strain in this area.

There are few outcrops of Shabogamo Gabbro adjacent to the window boundary. The most highly strained rocks are strongly foliated metagabbros (Plate 29) that have a fine-grained, granoblastic matrix composed of plagioclase and minor amounts of garnet, hornblende and biotite. The rocks contain medium- to coarse-grained clinopyroxene that has either a tattered habit, or is pseudomorphed by finer grained, granular clinopyroxene. The clinopyroxene is variably overprinted by hornblende and minor amounts of biotite. The foliation is defined by elongate clinopyroxene aggregates, hornblende and biotite. The occurrence of clinopyroxene, hornblende and biotite in highly strained Shabogamo Gabbro is compatible with the syn-high-strain amphibolite-facies minerals in both paragneiss and mafic gneiss in contiguous Lac Joseph terrane rocks.

Plate 29. *Highly strained Shabogamo Gabbro from near the margin of the tectonic window, Lac Joseph. Photo DJ-90-2301.*

Kinematic Sense, Displacement and Age

In the northeastern part of the study area, high-strain zones that make up the JMBZ contain an ensemble of kinematic indicators including C–S structures, shear bands (C' structures), asymmetric feldspar porphyroclasts and asymmetric minor folds (Plates 30 and 31). These demonstrate that the Lac Joseph terrane has been displaced toward the northwest, over the Molson Lake terrane. The kinematic indicators consistently gave this sense of displacement although the number of outcrops containing occurrences of unequivocal indicators was less than 15. Mineral elongation lineations in the JMBZ are dominantly southeast trending and moderately plunging. High-strain zones locally contain sheath folds (Plate 32).

Plate 30. *Photograph of a minor shear zone in Shabogamo Gabbro at Ossokmanuan Lake. The foliation and shear band structures demonstrate top side to the right (northwest) kinematic sense. Photograph is of a vertical face, looking toward the west-southwest. Photo DJ-90-2371.*

Around the margin of the tectonic window at Lac Joseph, there are several occurrences of kinematic indicators including C–S fabrics and shear band structures. These occur in rocks

Plate 31. *Feldspar porphyroclast demonstrating top side to the right (northwest) kinematic sense. The photograph is from the same outcrop and orientation as shown in Plate 30.*

Plate 32. *Sheath fold in mylonitic Shabogamo Gabbro, Ossokmanuan Lake. The photograph is of a vertical outcrop face, looking toward the northwest, perpendicular to the X-axis of the sheath fold. Photo DJ-90-237B.*

along the southwestern margin of the window in shear zones which are east-southeast- to southeast-striking, steeply southwest-dipping, and contain mineral lineations that plunge moderately toward the southeast. The kinematic indicators demonstrate a dextral sense of shear. If the effects of post-shearing folding are removed, and the mineral elongation lineations are restored to a horizontal, northwest-trending position, then the kinematic indicators are consistent with displacement to the northwest.

Based on mapping of rocks in the Molson Lake and Churchill Falls terranes by Nunn *et al.* (1984) and Connelly and Scowen (1987), and the position of the tectonic window, it is possible to estimate the most southerly extent of Shabogamo Gabbro and voluminous intrusions of Trans-Labrador batholith rocks (Figure 4). This places a constraint on the minimum amount of displacement on the JMBZ to be approximately 120 km, assuming that the displacement was consistently from southeast to northwest.

Structural and metamorphic relations in the JMBZ indicate that high strain was concomitant with amphibolite-facies conditions. In the Molson Lake terrane, the amphibolite-facies assemblages in highly strained rocks along the boundary are compatible with the amphibolite-facies assemblages in lesser strained rocks, which are not affected by the strain along the boundary, i.e., there is no apparent metamorphic difference between Molson Lake terrane rocks in the JMBZ and other Molson Lake terrane rocks in the study area. This relationship suggests that Lac Joseph terrane–Molson Lake terrane juxtaposition was approximately synchronous with the thermal peak of Grenvillian metamorphism in the Molson Lake terrane.

The age of the JMBZ is further constrained by the occurrence of a northeast-trending mafic dyke that is discordant to structures in a high-strain zone in paragneiss. In outcrop, the dyke is fine grained, massive and is undeformed by the high-strain structures. In thin-section, however, it is evident that the dyke is extensively recrystallized and weakly deformed. It is composed of fine-grained (0.3 mm), equant plagioclase grains that are surrounded by a very fine-grained ($\leq$0.04 mm) rim of recrystallized plagioclase. A minor amount of muscovite overprints the plagioclase. Orthopyroxene is similarly recrystallized, and forms equant to irregular-shaped grains ($\leq$0.5 mm) that are surrounded by a very fine-grained rim of granular orthopyroxene. Orthopyroxene is overprinted by a minor amount of hornblende and lesser biotite. In plagioclase, deformed twins and undulatory extinction demonstrate that the rocks were strained synchronous with the recrystallization. The fact that the dyke is discordant to fabrics in a high-strain zone, which is inferred to be related to the JMBZ, but is itself extensively recrystallized and weakly deformed, indicates that mafic magmatism and Grenvillian metamorphism outlasted the ductile strain in the JMBZ. Connelly (1988) has recognized similar mafic dykes and shear zone–mafic dyke relations in the JMBZ, along the southeast shore of Ossokmanuan Lake.

Alternatively, it could be argued that the shear zones, which the mafic dykes intrude, predate and are unrelated to the JMBZ. If this scenario was true, the mafic dykes could be related to either the Ossok Mountain or Shabogamo suites. However, as the shear zones have an attitude that is similar to the inferred attitude of the terrane boundary, and that these shear zones occur adjacent to the terrane boundary, the former model is proposed.

U–Pb geochronological studies by Connelly and Heaman (1993) of a mylonitized Trans-Labrador batholith rock from a shear zone along the JMBZ have shown that rocks contain, 1) strongly reset, discordant zircons, which yield a lower intercept age of 989 $\pm$ 12 Ma, and 2) titanite, which yields a concordant age of be 989 Ma, and is inferred, on the basis of texture, to have grown synchronous with the mylonitization. These ages are interpreted to represent the time of Grenvillian shearing in the JMBZ. Transport of the Lac Joseph terrane over the underlying rocks at ca. 990 Ma is supported by $^{40}Ar-^{39}Ar$ studies of retrogressed paragneiss in the Lac Joseph terrane, which suggest tectonic

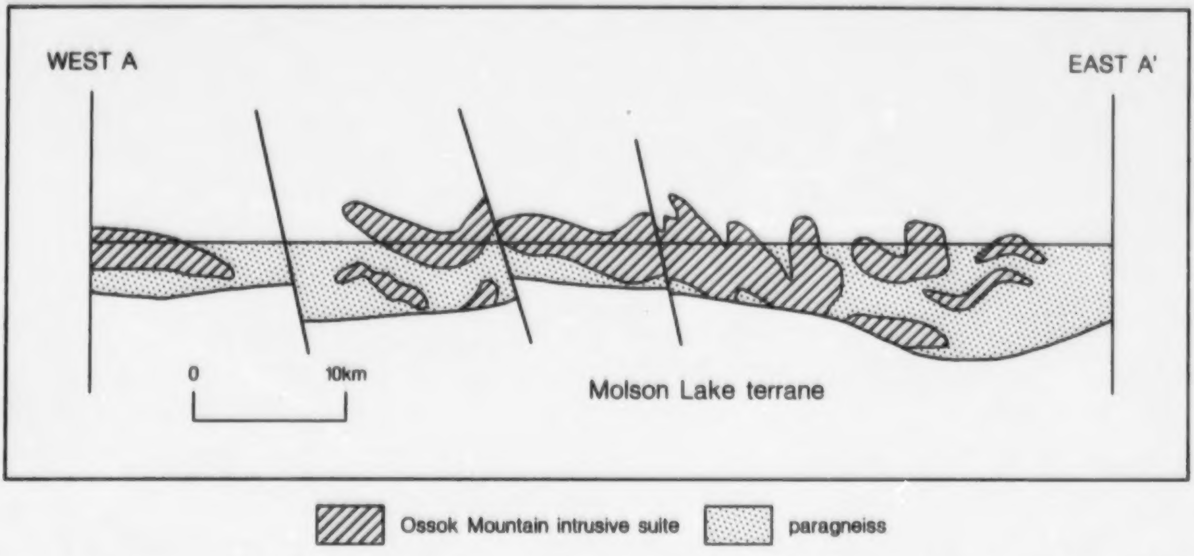


Figure 42. *Cross-section of the Lac Joseph terrane showing displacements on the northwest-striking faults. The line A-A' is shown in Figure 4.*

emplacement between 1000 and 990 Ma (Connelly *et al.*, 1990).

The age of metamorphism in the Molson Lake terrane, as indicated by the lower intercept ages of partially reset zircon in both Shabogamo Gabbro (1006 ± 7 Ma) and Trans-Labrador batholith rocks (995 ± 8 Ma) (ages from Connelly and Heaman, 1993), slightly predates and overlaps with the inferred age of tectonic juxtaposition with the Lac Joseph terrane. This conclusion is consistent with petrographic interpretation of the sheared rocks, which suggests ductile high-strain in the JMBZ was approximately synchronous with the thermal peak of Grenvillian metamorphism in the structurally lower rocks. The apparent coincidence in ages of metamorphism in the Molson Lake terrane and tectonic emplacement of the Lac Joseph terrane raises the problem of how the Lac Joseph terrane mainly escaped Grenvillian metamorphism and deformation. This problem is discussed in the final section (Tectonic Evolution, page 43).

LATE FAULTS

All rocks in the study area are deformed by northwest-striking (325°) and northeast-striking (055°) faults. The northwest-striking faults cut the JMBZ, thus they are constrained to be posttectonic with respect to shearing along the terrane boundary. The age relation between the two sets of faults is equivocal, although topographic lineament patterns suggest the northeast faults cut the northwest-striking faults. The faults are suspected to be late Grenvillian structures.

Outcrops along the faults are very rare, and their position is based mainly on topographic and magnetic anomaly lineaments. One occurrence of steeply east-dipping, protomylonitic paragneiss occurs along the inferred trace of a northwest-striking fault in the Lac Joseph terrane. Kinematic indicators in this outcrop demonstrate an oblique, dextral (footwall to the northwest), normal sense of displacement, and on this basis the northwest-striking faults are interpreted to be ductile normal faults. Displacements on the three northwest-striking faults that cut the JMBZ are estimated to be less than 2 km (Figure 42). Based on regional magnetic data, the westernmost of these faults has a strike length of approximately 150 km.

METAMORPHISM

METAMORPHISM OF THE LAC JOSEPH TERRANE

Metamorphic Minerals and Textures in Paragneiss

Paragneiss is metamorphosed to high grade throughout the Lac Joseph terrane. The rocks commonly contain sillimanite or kyanite, garnet and biotite, and have two phases of K-feldspar-bearing leucosome. There are a few occurrences of rocks that contain sillimanite, cordierite and K-feldspar. Sillimanite is the most widespread and abundant aluminum-silicate present, although in the northern part of the Lac Joseph terrane, adjacent to the boundary with the Molson Lake terrane, rocks contain kyanite, or kyanite and sillimanite. There are also local kyanite occurrences around the southwest margin of the tectonic window at Lac Joseph. Occurrences of paragneiss that contain stable orthopyroxene are rare, and these are restricted to aluminum-poor, sillimanite-absent rocks, which contain orthopyroxene and biotite.

U–Pb geochronological studies of monazite from the two leucosomes in the paragneiss yielded ages of 1660 ± 5 Ma and 1636 $^{+5}_{-4}$ Ma (Connelly and Heaman, 1993), and these have been interpreted to be the ages of leucosome formation. Thus, the high-grade metamorphism of the paragneiss is entirely Labradorian. These ages are consistent with concordant U–Pb zircon ages of 1647 Ma and 1645 Ma (Krogh, 1983) from a granulite-facies monzogranite in the eastern part of the Lac Joseph terrane, and are inferred to represent the age of metamorphism.

Sillimanite occurs as fine- to medium-grained acicular blades, less commonly as fibrolitic mats, and as blue-grey-weathering, medium- to coarse-grained sillimanite–quartz nodules. Sillimanite porphyroblasts occur either as 1) randomly aligned on the S_2 foliation surface, or 2) intensely aligned porphyroblasts on S_2 that are parallel to F_2 fold axes, or 3) aligned parallel to F_3 fold axes. These relations suggest that growth of Labradorian sillimanite persisted throughout Labradorian deformation in the Lac Joseph terrane. Inclusions of spinel in sillimanite are rare. Locally, the sillimanite-bearing rocks also contain cordierite that is fine- to medium-grained and variably pseudomorphed by pinite. The cordierite-bearing rocks lack garnet.

The northeastern part of the Lac Joseph terrane has several occurrences of paragneiss that contain sillimanite and orthopyroxene. The orthopyroxene is very fine grained (≤0.01 mm), and forms fine-grained, granular aggregates that may be the recrystallized relics of orthopyroxene porphyroblasts. The aggregates occur within sillimanite lenses containing biotite and magnetite. The sillimanite, biotite and magnetite appear to overgrow orthopyroxene, and on this basis it is presumed that the orthopyroxene is metastable with sillimanite.

Garnet is fine to coarse grained, and commonly poikiloblastic containing biotite, sillimanite and magnetite inclusions. Commonly, the inclusions are aligned parallel to S_2 in the surrounding matrix, demonstrating that at least locally, garnet growth outlasted S_2.

In the northern part of the study area, kyanite occurs as fine-grained, stubby prismatic grains having maximum lengths rarely exceeding 0.5 mm. Locally, aggregates of fine-grained kyanite form knots that may be the pseudomorphed relics of once coarser grained kyanite porphyroblasts. In rocks where kyanite is abundant (≥ 10 percent), kyanite and biotite form thin layers that define the S_2 foliation and gneissosity. The fine-grained habit of kyanite is presumed to be chiefly a function of strain and recrystallization under high-grade conditions. There is no indication from the texture that kyanite is a pseudomorphic mineral, or that it grew at the expense of an earlier phase.

In rocks that contain kyanite and sillimanite, the sillimanite occurs as very fine-grained needles and as fine- to medium-grained acicular porphyroblasts. In some of the kyanite–sillimanite rocks, the presence of aggregates of granular kyanite that are surrounded by sillimanite suggests that sillimanite postdates and overgrows kyanite, although in other rocks the kyanite–sillimanite relations are equivocal, and locally, kyanite appears to be texturally stable with sillimanite.

The kyanite is inferred to be a Labradorian mineral based on the textural equilibrium between kyanite and all of biotite, garnet, and K-feldspar, and the fact that kyanite + biotite layers define a northeast- to northwest-striking foliation that is interpreted to be the Labradorian S_2 foliation. The inference from the textures that sillimanite overprints kyanite is consistent with the interpretation that the kyanite in the northern part of the study area is a prograde, Labradorian mineral.

Fine-grained, prismatic kyanite occurs locally in paragneiss around the margin of the tectonic window at Lac Joseph. The age of this kyanite is equivocal and remains an outstanding problem. $^{40}Ar-^{39}Ar$ studies of the Lac Joseph terrane rocks may help to independently evaluate the Grenvillian thermal history of this area. The 1001 ± 7 Ma U–Pb titanite age obtained from a granitoid gneiss, which occurs north of the kyanite-bearing paragneisses, suggests Grenvillian metamorphism of this part of the Lac Joseph terrane may be more significant that previously appreciated.

Interpretation

The ubiquitous occurrence of K-feldspar-bearing leucosomes in semipelitic and pelitic paragneiss in the Lac Joseph terrane demonstrates that the rocks were metamorphosed to high grade in the Labradorian Orogeny. In the central part of the terrane, the presence of coexisting sillimanite, garnet and biotite, local cordierite-bearing rocks,

and rare orthopyroxene and biotite-bearing rocks suggests temperatures of ≤750°C (D.M. Carmichael, unpublished petrogenetic grid, Pattison and Tracy, 1991). Equilibrium pressures in the central part of the terrane are presumed to be less than 7 kbar based on the preponderance of sillimanite-bearing rocks, and the absence of stable, coexisting orthopyroxene and sillimanite. In contrast, the occurrence of Labradorian kyanite along the northern margin of the terrane suggests that Labradorian paleopressure, and thus, paleodepth increases toward the northern margin of the Lac Joseph terrane to Bathozone 5 (Carmichael, 1978) conditions (>7 kbar).

The paragneiss is locally retrogressed and contains the assemblage biotite and muscovite. The muscovite is presumed to be the result of the breakdown of sillimanite and K-feldspar. The retrogression occurs in rocks in the northeastern part of the Lac Joseph terrane, which contain Grenvillian high-strain structures related to the JMBZ, and locally in rocks around the margin of the tectonic window. In the latter case, the retrogression occurs in rocks that are both highly strained, presumably in structures related to the JMBZ, and also in rocks that are much lesser strained but occur within several kilometres of the terrane boundary. Retrogression of the lesser strained rocks, in which the retrogression cannot be attributed to recrystallization and hydration in the JMBZ, may be related to an influx of water, derived from the lower structural nappe (Molson Lake terrane) or from the JMBZ, attendant and subsequent to terrane accretion.

Metamorphic Minerals and Textures in Mafic Rocks

The rocks of the Ossok Mountain intrusive suite are variably metamorphosed from granulite facies containing two pyroxenes and plagioclase, to amphibolite facies containing hornblende and plagioclase, or hornblende, clinopyroxene and plagioclase. The relation between the granulite-facies rocks and amphibolite-facies rocks is retrogressive.

The igneous age of the Ossok Mountain intrusive suite, determined to be ca. 1640 to 1620 Ma based on U–Pb zircon and rutile geochronology, is approximately synchronous with Labradorian metamorphism in the Lac Joseph terrane, determined from the ages of the leucosomes in paragneiss. Thus, the mafic rocks were recrystallized under high-grade conditions by the same Labradorian high-grade event that affected the paragneiss shortly after their intrusion. The overlapping of rutile and zircon analyses in a sample of Ossok Mountain gabbro from the study area (Appendix 1) demonstrates that the metamorphism is entirely Labradorian, and implies that temperatures during the Grenvillian Orogeny were below the blocking temperature of rutile, estimated to be 400°C (Connelly, 1992).

The expression of high-grade Labradorian metamorphism in the mafic rocks is varied; rocks are mainly recrystallized and have granoblastic, regional-metamorphic textures, although locally, rocks have well-preserved igneous textures and mineralogy. This variability can occur at the outcrop scale, and is presumed to be the result of differences in pre-metamorphic (i.e., igneous) textures. In the field, it is chiefly the coarse-grained rocks, which have preserved igneous characteristics, whereas the fine-grained rocks have granoblastic, metamorphic textures and better development of foliation. This observation suggests that coarser grained rocks were less tractable to recrystallization and development of a Labradorian foliation as compared to rocks that were originally finer grained. It is also possible that some rocks that have well-preserved igneous textures and mineralogy, and have an isotropic structure, are late intrusive phases of the Ossok Mountain intrusive suite that postdated the peak of Labradorian metamorphism and deformation.

The recrystallized rocks are fine to medium grained and have granoblastic textures defined by equigranular orthopyroxene, clinopyroxene and plagioclase. Locally, the granoblastic rocks have relics of plagioclase or pyroxene phenocrysts and these are variably replaced by granoblastic aggregates of plagioclase or pyroxene, respectively. A few rocks contain biotite that appears to be in textural equilibrium with the pyroxenes, and the rocks contain rare, fine-grained spinel that is inferred to be metamorphic.

In the northeastern Lac Joseph terrane, in areas that have mainly two-pyroxene granulite-facies rocks, there are several occurrences of coronitic mafic rocks. The coronitic rocks have a massive structure and preserve an igneous, intergranular texture. The rocks contain olivine armoured by an inner corona of bladed orthopyroxene and an outer corona of clinopyroxene–spinel symplectite. The symplectite contains minor biotite inclusions. Biotite also forms overgrowths on spinel. Rivers and Mengel (1988) have concluded that the formation of symplectite coronas around olivine in the Lac Joseph terrane is compatible with a single-stage reaction during isobaric cooling following igneous emplacement. Consistent with this conclusion is the observation that these rocks are massive and preserve an igneous texture, and although they are surrounded by granulite-facies rocks, the coronitic textures are not interpreted to be Labradorian metamorphic features.

The two-pyroxene granulite-facies rocks have been variably retrogressed to amphibolite-facies. Based on the extent of retrogression, mafic rocks can be subdivided into three metamorphic zones. These are identified as Zone I, Zone II and Zone III (Figure 43). Placing the boundaries between the zones is somewhat subjective, and they are inferred to be transitional, perhaps over several kilometres. In some areas, the transitional aspect of the boundaries is so extensive that zones are defined on the basis of containing mainly one rock type, but having a significant minority of another rock type.

Zone I rocks are essentially non-retrogressed, two-pyroxene granulites that may contain very minor amounts of amphibolite-facies minerals. Typically, these rocks have granoblastic textures and are variably foliated. They may contain minor amounts (≤5 percent) of hornblende and biotite, which have grown along the margins of pyroxene

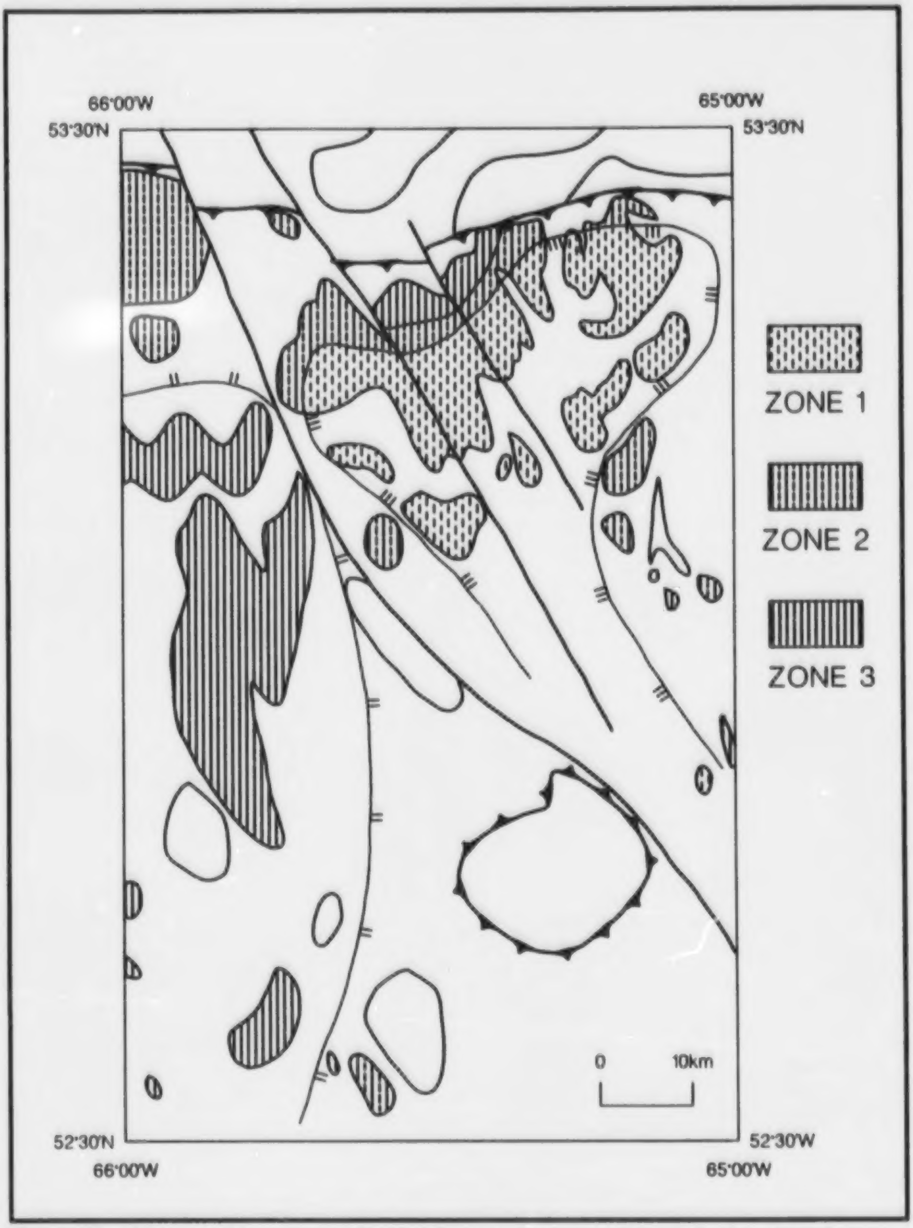


Figure 43. *Metamorphic zones in Ossok Mountain intrusive suite rocks, Lac Joseph terrane.*

grains. Relict igneous minerals and textures occur locally in Zone I rocks.

Zone II rocks contain relics of granulite-facies pyroxenes, and local igneous pyroxenes, but these are more extensively overprinted by amphibolite-facies minerals than in Zone I rocks. Hornblende is the most common amphibolite-facies mineral present; it occurs both as overgrowths and pseudomorphs of pyroxene, and as discrete hornblende. In Zone II rocks, the percentage of hornblende can be equal to, or exceed the percentage of pyroxene; biotite is common. Garnet appears in Zone II rocks and forms either discrete grains, or coronas on opaque minerals, and rarely on orthopyroxene. Titanite is a relatively common metamorphic mineral in Zone II rocks.

Zone III rocks are extensively overprinted by amphibolite-facies retrogression. They are characterized by hornblende ± garnet, or hornblende + clinopyroxene ± garnet assemblages, and contain only very rare orthopyroxene. Orthopyroxene occurs as extensively overprinted relics of high-grade metamorphic or igneous

grains. Clinopyroxene occurs either as relics within hornblende grains, or as granoblastic grains that appear to be in textural equilibrium with hornblende and plagioclase. Clinopyroxene-absent rocks in Zone III are common. Garnet is common in Zone III rocks, and it is in apparent textural equilibrium with hornblende and plagioclase, and locally with clinopyroxene. Minor biotite, scapolite, apatite and titanite are common; epidote occurs locally.

Interpretation

The presence of stable, metamorphic orthopyroxene, clinopyroxene and plagioclase in Zone I mafic rocks suggests equilibrium temperatures and pressures that are consistent with those inferred from assemblages in contiguous paragneiss. The two-pyroxene rocks are thought to have been once more widespread than at present, based on the textural evidence of a retrogressive relation between Zone I and Zone II rocks, but it is uncertain if all of the mafic rocks in the Lac Joseph terrane once contained metamorphic orthopyroxene.

The amphibolite-facies retrogression in Zone II and Zone III rocks is inferred to be a late-syn (Labradorian) metamorphic feature based on the fact that amphibolite-facies minerals are growing along the principal foliation in the retrogressed rocks. In Zone II and Zone III rocks, the principal foliation is defined to be a Labradorian structure (S_2) because the foliation is structurally concordant to, and thus correlated with, the Labradorian S_2 in contiguous paragneiss. The S_2 foliation in paragneiss, which is adjacent to retrogressed mafic granulite, is defined by the high-grade assemblage and the transposed leucosomes.

The conclusion that the amphibolite-facies retrogression of the mafic rocks in the Lac Joseph terrane is Labradorian based on the preceding textural and structural arguments is consistent with U–Pb geochronological evidence suggesting the Lac Joseph terrane did not experience significant Grenvillian heating (Rivers and Nunn, 1985; Connelly *et al.*, 1990; and Appendix 1). Petrographic studies by Rivers and Mengel (1988) of mafic rocks in the Lac Joseph terrane are in agreement, and they conclude that the rocks show no apparent signs of a Grenvillian imprint.

There are also Zone III-type rocks in the northeastern part of the Lac Joseph terrane in areas that are adjacent to and within the JMBZ. Commonly, but not in all cases, these retrogressed mafic rocks are strongly foliated or mylonitic, and contain amphibolite-facies minerals which have grown along the high-strain fabric. On the basis of orientation, these structures are inferred to be Grenvillian and related to the JMBZ. Thus, the amphibolite-facies retrogression is also inferred to be Grenvillian and synchronous with the high-strain event. Some of the Zone III-type retrogressed rocks in this area are not highly strained, although the retrogression is suspected as being Grenvillian based on the proximity of the rocks to the JMBZ.

There are no Ossok Mountain intrusive suite rocks around the margin of the tectonic window at Lac Joseph, although mafic supracrustal rocks that occur in the southwest end of Lac Joseph, and which have suspected Grenvillian structures, are amphibolites that contain hornblende, plagioclase and epidote. The rocks do not contain pyroxene. Grenvillian amphibolite-facies metamorphism in the mafic rocks in this area is consistent with the grade of Grenvillian retrogression in contiguous paragneiss.

METAMORPHISM OF THE MOLSON LAKE TERRANE

Shabogamo Gabbro and Trans-Labrador batholith rocks, both in the northern part of the study area and in the tectonic window at Lac Joseph, variably display the effects of a medium-grade tectonothermal event. The age of this event is presumed to be Grenvillian based on, 1) a U–Pb lower intercept age of 966 ± 30 Ma from baddeleyite, having zircon overgrowths, in Shabogamo Gabbro at Lac Joseph, and 2) U–Pb zircon studies of Shabogamo Gabbro and Trans-Labrador batholith rocks in the Molson Lake terrane by Connelly *et al.* (1990) and Connelly and Heaman (1993), which gave metamorphic ages between 1006 and 995 Ma. These ages are in agreement with results of U–Pb studies of titanite from Churchill Falls terrane rocks which yielded metamorphic ages between 1000 and 990 Ma (Rivers and Nunn, 1985).

In Shabogamo Gabbro and Trans-Labrador batholith rocks that occur east of the study area, Grenvillian metamorphism reached amphibolite-facies (Rivers and Nunn, 1985), and locally may have been high enough to produce migmatites (Nunn and Christopher, 1983). In the southwestern Molson Lake terrane, Connelly *et al.* (1989) and Indares (1991) have shown that Grenvillian temperatures reached 750°C and pressures may have exceeded 15 kbar (Indares, 1993). A regional distribution of Grenvillian isograds in areas west of the Lac Joseph terrane is shown in Figure 44.

Metamorphic Minerals and Textures in the Shabogamo Gabbro

The Shabogamo Gabbro contains a spectrum of structures and textures ranging from massive, fresh olivine gabbro that has a completely preserved intergranular texture and cumulate structure, to massive coronitic rocks, to strongly foliated rocks containing granoblastic, metamorphic textures and amphibolite-facies minerals. Generally, the rocks that are the most highly strained also show the most pervasive effects of recrystallization and growth of metamorphic minerals.

In the Ossokmanuan Lake area, olivine commonly has a multiple corona consisting of an inner corona of orthopyroxene and an outer corona of garnet (see Plate 13). Commonly, the inner corona has two textural zones including an inner, massive or intact zone and an outer zone of bladed or granular orthopyroxene. Relict orthopyroxene phenocrysts

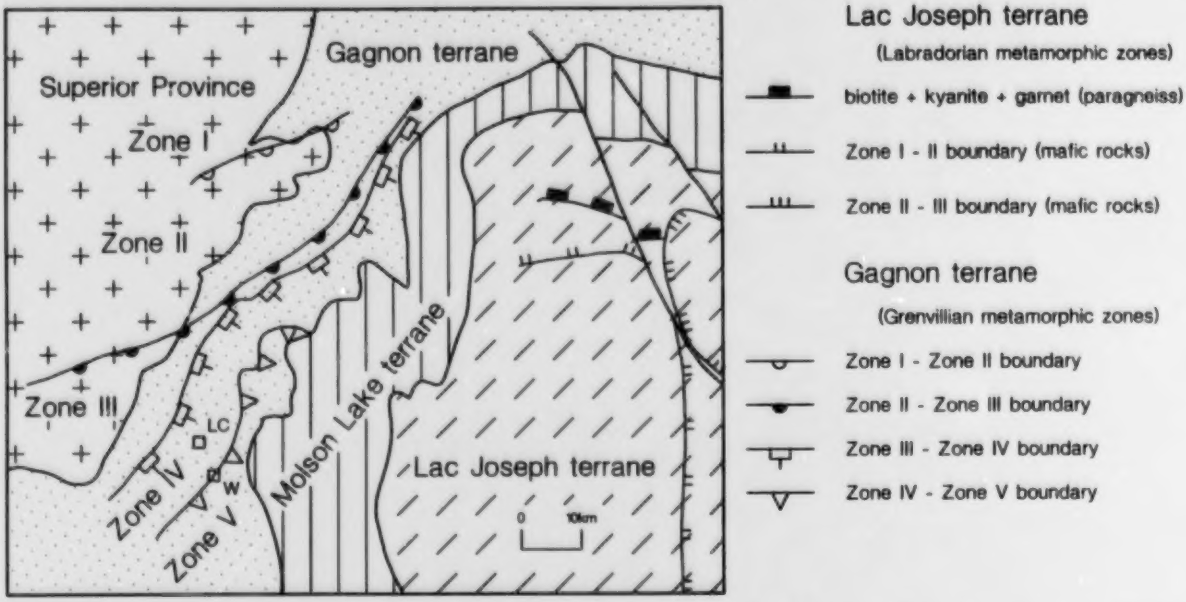


Figure 44. *Grenvillian metamorphic isograds in the region west of the Lac Joseph terrane. Zone I—muscovite + chlorite, Zone II—chlorite + biotite, Zone III—muscovite + biotite + chlorite, Zone IV—muscovite + kyanite + garnet + biotite, Zone V—muscovite + kyanite + garnet + biotite + granitic veins, LC—Labrador City, W—Wabush. Metamorphic zones in the Lac Joseph terrane are shown in Figure 43. Modified from van Gool (1992).*

also have coronas that consist of a single, amphibole corona, or a multiple corona of amphibole (inner corona) and garnet (outer corona). In some rocks, the contact between the orthopyroxene core and the amphibole corona is marked by fine-grained biotite. Inclusions of both fine-grained biotite and an opaque mineral also occur within the amphibole corona. The Ossokmanuan Lake area also has rocks which have preserved igneous textures, but contain up to 20 percent garnet. The garnet occurs as coronas around both orthopyroxene and ilmenite, and as fine-grained, euhedral grains that are ubiquitous. The coronas indicate amphibolite-facies metamorphism of the Shabogamo Gabbro.

Multiple coronas of biotite (inner corona) and garnet (outer corona) also occur around ilmenite, although Rivers and Mengel (1988) have interpreted the biotite corona to be an igneous feature based on the observation that biotite coronas on ilmenite are observed in Shabogamo Gabbro north of the Grenville Front.

In Shabogamo Gabbro, deformed in the JMBZ in the Ossokmanuan Lake area, rocks that contain a strong Grenvillian foliation or a mylonitic fabric are completely recrystallized to hornblende- and garnet-bearing amphibolite. Clinopyroxene occurs only rarely as cores within hornblende grains. Plagioclase laths are recrystallized, producing a granoblastic texture, and medium-grained garnet porphyroblasts are ubiquitous.

In the Lac Joseph area, relict igneous olivine grains are found in massive and weakly foliated Shabogamo Gabbro. Olivine, variably replaced by iddingsite, is enveloped by an inner corona of bladed or granular orthopyroxene, a complex middle corona of garnet that has abundant pyroxene inclusions, and an outer corona of garnet (Plate 33). The middle, inclusion-rich corona and the outer, inclusion-absent corona are textural variations of the same, single garnet corona. In some rocks, the inner corona of orthopyroxene is separated from garnet by a thin and discontinuous corona of amphibole. Garnet—plagioclase contacts are locally marked by thin and discontinuous muscovite layers. Local clinopyroxene phenocrysts have identical corona structures as those around the olivine grains. Multiple coronas of biotite and garnet have formed around ilmenite.

As in the highly strained rocks in the JMBZ in the Ossokmanuan Lake area, the rocks with strong Grenvillian fabrics in the Lac Joseph area are pervasively overprinted by amphibolite-facies minerals. In the Lac Joseph area, the highly strained rocks are fine- to medium-grained amphibolites which contain hornblende, plagioclase, biotite and local quartz. Locally, rocks contain coarse-grained clinopyroxene porphyroblasts that are variably overgrown by hornblende and, to a lesser extent, by fine-grained biotite. Some foliated amphibolites contain fine-grained garnet that occur throughout the rocks. The highly strained rocks have neither relict igneous nor coronitic textures.

Amphibolite-facies assemblages in foliated and highly strained Shabogamo Gabbro in the Lac Joseph area, are compatible with assemblages in mafic gneiss in the adjacent Lac Joseph terrane. The age of amphibolite-facies

Plate 33. *Photomicrograph of multiple corona consisting of orthopyroxene (opx), bladed orthopyroxene (bopx) and garnet (grt) that armours olivine (olv) in Shabogamo Gabbro at Lac Joseph. The inner part of the garnet corona (dusty appearance) contains abundant, fine-grained opaque inclusions. Photo DJ-90-2302.*

metamorphism in contiguous Lac Joseph terrane rocks is also inferred to be Grenvillian.

Interpretation

All of the existing U–Pb isotopic evidence indicates that the Molson Lake terrane was pervasively affected by Grenvillian metamorphism, and that rocks have not been affected by any thermotectonic events in the range 1600 to 1000 Ma (Jim Connelly, personal communication 1993). This suggests that the amphibolite- to eclogite-facies corona structures in the Molson Lake terrane are Grenvillian textures rather than being related to subsolidus equilibration following intrusion at depth.

The interpretation that the medium- to high-pressure metamorphism in the Molson Lake terrane is an entirely Grenvillian phenomenon, leads to several important questions about its history. First, what was the depth of intrusion of Shabogamo Gabbro in the Molson Lake terrane, and what was the crustal residence time for the intrusions at that depth? And second, what was the Grenvillian load that produced eclogitic rocks in the Molson Lake terrane?

Emplacement of the Lac Joseph terrane on the underlying Molson Lake terrane could neither have preceded development of the high-pressure metamorphism nor significantly abetted in the Grenvillian burial of the Gagnon, Molson Lake and Churchill Falls terranes. This is suggested by the structural relations between corona gabbro and non-corona amphibolite-facies gabbro in the JMBZ, and U–Pb isotopic studies that demonstrate the Lac Joseph terrane mainly escaped Grenvillian heating (Rivers and Nunn, 1985; Connelly *et al.*, 1990; and this study). However, the isotopic data also dictates that footwall rocks be uplifted rapidly prior to their ca. 990 Ma accretion with the overriding Lac Joseph terrane. Rapid uplift of the Molson Lake terrane is supported by steep, isothermal P–T cooling paths derived from both Shabogamo Gabbro and country rocks (Indares, 1991).

In spite of the isotopic evidence, which suggests that eclogitic Shabogamo Gabbro did not have a long, deep-crustal residence time, there remains the possibility that the Shabogamo Gabbro was intruded to at least mid-crustal depths and remained there until Grenvillian loading. There is also the possibility that the Molson Lake terrane is composed of several structural slices with distinctly different Grenvillian thermal histories. Further isotopic, thermobarometric and geophysical studies are required to better understand the history and internal structure of the poorly exposed Molson Lake terrane.

ECONOMIC GEOLOGY

Previously reported mineralization is restricted to occurrences of disseminated pyrite within gabbroic rocks, and disseminated chalcopyrite and pyrite at the Wynne Showing, UTM coordinates 365450 E, 5865900 N (Newfoundland Department of Mines and Energy, 1976). Table 4 lists Cr and Ni values in serpentinzed troctolite from the Wynne Showing. The ultramafic rock is tentatively correlated with the Ossok Mountain intrusive suite.

Mapping in 1990 revealed common, but minor, occurrences of disseminated pyrite in both the Ossok Mountain intrusive suite rocks, and in the supracrustal rocks in the Lac Joseph terrane. Several of the more notable gossans occur in gabbronorite at 334550 E, 5885250 N, and 355100 E, 5919300 N, and in supracrustal rocks at 334050 E, 5885250 N. The Shabogamo Gabbro also contains local occurrences of minor, disseminated pyrite.

Table 4. Nickel and chromium contents in serpentinized mela-troctolite dyke located in the southeastern part of the study area. (UTM coordinates 365450 E 5865900 N)

Sample	Nickel (ppm)	Chromium (ppm)
1. GN-85-W5	2810	9050
2. GN-85-W6	2700	7280
3. DJ-90-W1	3300	8850
4. DJ-90-W4	2740	6330

Analyses 1 to 4 by Becquerel Laboratories Inc. Neutron activation analysis.

5. GN-85-W5	3275	45
6. GN-85-W6	3275	45
7. DJ-90-W1	2820	40
8. DJ-90-W2-1	2675	433
9. DJ-90-W2-2	3010	504
10. DJ-90-W3	2475	134

Analyses 5 to 10 by Bondar-Clegg Laboratories.

Table 5. Selected metal contents of the Ossok Mountain intrusive suite and the Shabogamo Gabbro

		(values in ppm)							(values in ppb)		
SAMPLE	UNIT	Cu	Pb	Zn	Ni	Cr	Mo	Co	Au	Pd	Pt
01	OM	39	7	88	17	100	4	25	-2	4	-10
02	OM	56	116	5	69	208	4	36	-2	-2	-10
03	OM	98	-1	66	157	325	3	39	-2	24	10
04	OM	15	118	6	78	237	4	29	-2	4	-10
05	OM	14	3	91	166	108	4	37	-2	6	-10
06	OM	39	3	128	46	91	3	27	4	4	-10
07	OM	115	1	127	121	134	4	42	12	10	-10
08	OM	39	128	8	68	220	4	32	4	10	20
09	OM	52	-1	63	243	285	4	43	54	200	30
10	OM	54	-1	66	325	155	4	49	-2	-2	-10
11	OM	94	54	-1	318	514	3	42	6	20	10
12	OM	96	-1	61	699	45	3	61	-2	-2	-10
13	SH	73	5	108	132	129	3	41	-2	20	10
14	SH	82	132	6	158	77	4	49	6	2	5
15	SH	43	119	9	38	37	3	34	-2	-2	-10
16	SH	63	139	6	69	183	4	38	-2	-2	-10
17	SH	20	58	-1	328	225	4	46	-2	-2	15
18	SH	48	124	1	56	191	4	38	4	-2	-10
19	SH	31	151	2	69	172	5	44	-2	-2	-10
20	SH	35	119	-1	89	84	4	42	-2	-2	10
21	SH	36	-1	69	152	44	4	39	-2	20	-10
22	SH	21	67	-1	130	89	3	34	-2	2	-10
23	SH	20	84	-1	103	183	5	35	2	-2	-10

Negative sign indicates less than the specified value.
OM=Ossok Mountain intrusive suite
SH=Shabogamo Gabbro

Analysis by the Newfoundland Department of Mines and Energy chemical laboratory.

The aforementioned sulphide showings are only minor, although layered gabbronoritic and gabbroic rocks belonging to both the Ossok Mountain intrusive suite and the Shabogamo Gabbro have potential for nickel and PGE mineralization. Table 5, and Appendix 2, lists values of Ni, Cr, Au, Pd, and Pt that were measured in the course of a geochemical study of some representative samples from both mafic intrusive suites. In addition, the supracrustal rocks in the Lac Joseph terrane have some potential for preserving base-metal occurrences of sedimentary exhalative origin (Swinden *et al.*, 1991).

Meyer (1989) reports muscovite-bearing pegmatites that were intersected by road construction at kilometre 90 and kilometre 137 (measured from Labrador City) on the Trans-Labrador Highway. These occurrences may have potential for high-quality sheet muscovite.

TECTONIC EVOLUTION

LABRADORIAN HISTORY

The oldest unit in the study area is the paragneiss, which makes up most of the Lac Joseph terrane and is a significant component of Labradorian crust exposed in several Grenvillian terranes to the east. It is inferred to be derived from an extensive belt of greywacke–mudstone turbidite. Minimum estimates for the pre-Labradorian dimensions of the sedimentary basin suggest its size was comparable to some of the Archean, turbidite-dominated metasedimentary belts in the Superior Province, or to the Early Proterozoic Kisseynew Gneiss Belt in the Trans-Hudson Orogen.

Sediments in the aforementioned analogues were probably deposited in basins associated with temporally equivalent volcanic arcs. The predominant, isotopically juvenile character of the paragneiss in Labrador is compatible with an Early Proterozoic arc-basin environment (Wardle *et*

al., 1991), although U–Pb studies of inferred detrital zircons yielding Archean ages (e.g., Thomas *et al.*, 1983) demonstrate that at least some of the sedimentary detritus was derived from an older provenance, perhaps the craton to the north. The sediments in the Lac Joseph terrane, and the Labradorian terranes to the east were probably derived from Lower Proterozoic volcanic rocks in the Makkovic Province (Kerr *et al.*, 1992) and/or from Lower Proterozoic (pre-1.87 Ga) volcanic rocks in the New Quebec Orogen. These sediments were then deposited along the southern margin of pre-Middle Proterozoic Laurentia as rise- and slope-facies sediments of a continental margin prism.

The preceding interpretation implies that the Labradorian paragneiss is parautochthonous with respect to the craton to the north. Stratigraphic contacts between the paragneiss and the craton are not preserved due to a combination of elimination by intrusions of the Trans-Labrador batholith and Grenvillian thrusting.

This model does not account for the possibility of major stratigraphic discontinuities in the Labradorian paragneiss. It is conceivable that the Metasedimentary Gneiss terrane (Wardle *et al.*, 1991) consists of a tectonic collage of fundamentally different sequences. Some of the sediments may have been relatively young and related to ca. 1720 to 1700 Ma tectonic and plutonic events recognized in southeastern Labrador (e.g., Wardle *et al.* 1991, Gower *et al.*, 1992). Gower *et al.* (1992) have also identified metasedimentary rocks in a Labradorian terrane in eastern Labrador, inferred to be derived from sediments deposited after 1627 Ma (based on U–Pb isotopic data). Further mapping and isotopic studies are necessary to better constrain the sedimentary provenance and age of the paragneiss in the Lac Joseph terrane.

In western Labrador, early- to mid-Labradorian (1680 to 1640 Ma) contraction of the sedimentary belt against the margin of Laurentia was approximately synchronous with, and terminated by, intrusion of ca. 1650 Ma plutons of the Trans-Labrador batholith and gabbronorite and gabbro, represented by the ca. 1640 to 1620 Ma Ossok Mountain intrusive suite, the former welding the supracrustal rocks to the craton. The widespread and voluminous plutonism represented by the Trans-Labrador batholith suggests that significant crustal thickening must have occurred by this time in order to permit generation of such large volumes of granitic magma (Ryan, 1984; Kerr, 1989a; Wardle *et al.*, 1991). A significant portion of the Trans-Labrador batholith may be derived from anatectic melting and recycling of older crust during crustal thickening (Wardle *et al.*, 1986), although major- and trace-element chemistry, and isotopic compositions are not inconsistent with interpretations of this belt as a subduction-related, continental magmatic arc (Kerr, 1989b). Chemistry of the temporally associated Ossok Mountain intrusive suite indicates it may also have formed in a magmatic arc setting, suggesting Labradorian mafic magmatism may be genetically related to the granite plutonism that was concentrated along the margin of the craton.

Thomas (1981) demonstrated that in areas east of the Lac Joseph terrane, Trans-Labrador batholith magmatism postdated the onset of Labradorian metamorphism and deformation, a model which has been subsequently corroborated by both by U–Pb geochronology of metamorphic zircons in paragneiss (e.g., Krogh, 1983; Currie and Loveridge, 1985) and by field relations described by Wardle *et al.* (1991). In contrast, U–Pb geochronology in the Lac Joseph terrane suggests' Trans-Labrador batholith intrusions are roughly synchronous with the high-grade metamorphism. The latter relation suggests that in the Lac Joseph terrane, some or most of the heat supply for the high-grade, low- to medium-pressure Labradorian metamorphism of sediments and mafic intrusions may have been from approximately syn-metamorphic Trans-Labrador batholith plutons, consistent with models of high-grade metamorphism in Phanerozoic magmatic arcs (e.g., Windley, 1981).

The Labradorian history of metamorphism, deformation and intrusion is uncertain for the Molson Lake and Churchill Falls terranes, although there is no evidence to suggest that the Lac Joseph and Molson Lake–Churchill Falls terranes were separate tectonic entities prior to the Grenvillian Orogeny. The relative abundance of Trans-Labrador batholith intrusions in the Churchill Falls and Molson Lake terranes compared to the Lac Joseph terrane, suggests that Labradorian gneisses, which would later constitute the Grenvillian Lac Joseph terrane, lay to the present-day southeast of the main part of the Trans-Labrador batholith during the Labradorian Orogeny.

Labradorian contraction, crustal thickening and plutonism may have been in response to consumption of oceanic crust in an approximately northwest-dipping subduction zone, and collision with terranes that lay to the southeast of pre-Middle Proterozoic Laurentia (Figure 45). These terranes are missing in northeastern Laurentia, although possible evidence of them might be found southeast of the 1690 to 1620 Ma Mazatzal Province in the southwestern United States.

Following the Labradorian Orogeny, rocks in the Churchill Falls and Molson Lake terranes were intruded by the ca. 1455 Ma Shabogamo Gabbro. Based on major- and trace-element chemistry, the Shabogamo Gabbro can be classified as a within-plate basalt, and is part of a widespread period of anorogenic mafic magmatism that lasted approximately 250 Ma in the hiatus between the Labradorian and Grenvillian orogenies (Gower *et al.*, 1991a). The apparent absence of Shabogamo Gabbro in the Lac Joseph terrane further constrains the pre-Grenvillian position of the Lac Joseph terrane, requiring that it lay to the present-day southeast of the most southerly occurrences of Shabogamo Gabbro.

Connelly and Heaman (1993) report a concordant U–Pb monazite age of 1403 Ma, and monazite ages between 1423 and 1399 Ma, from a retrogressed paragneiss, and concordant U–Pb titanite ages of 1281 Ma from an amphibolite-facies mafic gneiss, both from the Lac Joseph terrane. These ages

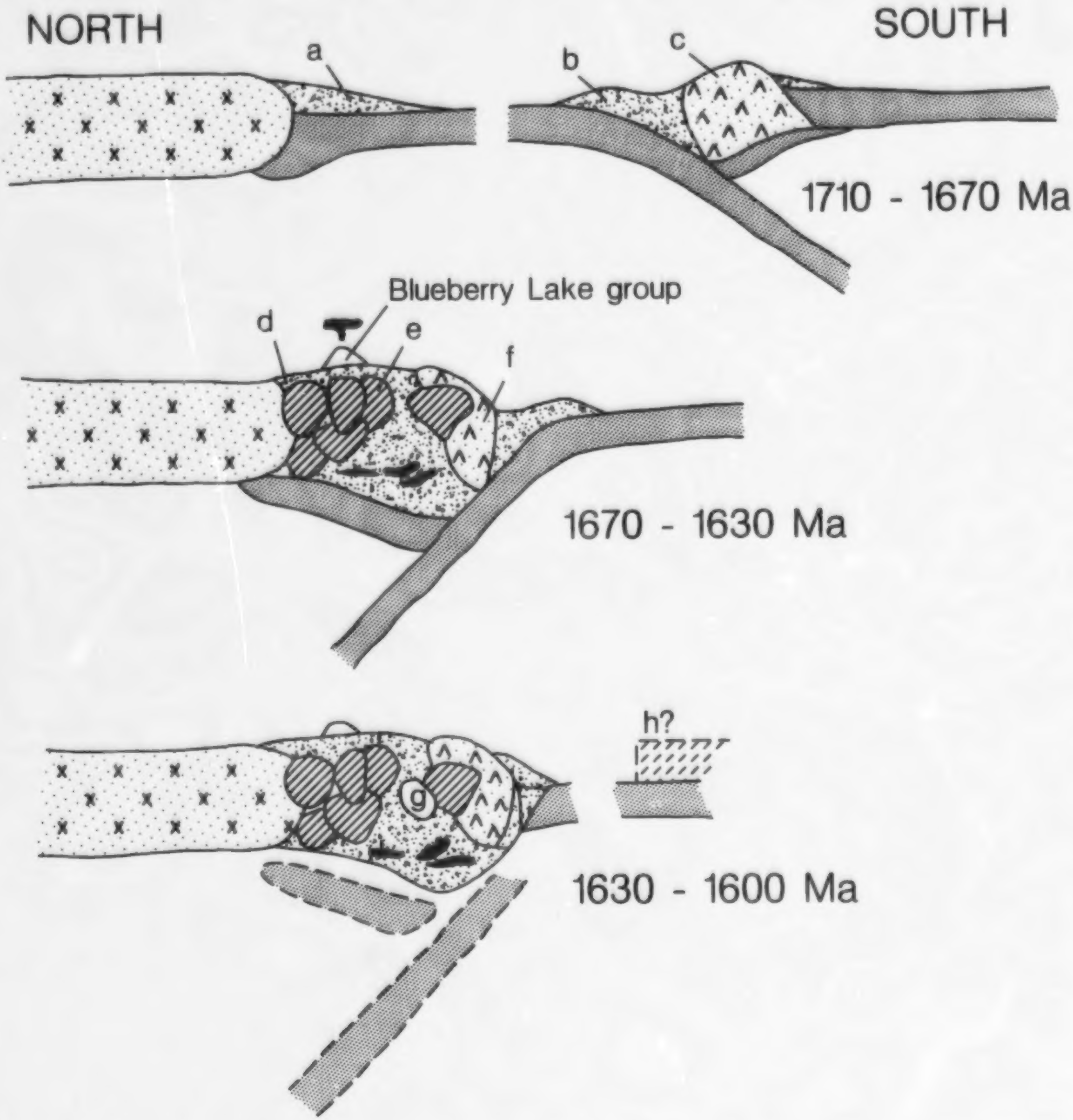


Figure 45. *Possible model for Labradorian tectonic evolution in the northeastern Grenville Province.* top—*Early Labradorian (ca. 1710 to 1670 Ma). A magmatic arc (c) and associated volcaniclastic sediments (b) form above a south-dipping subduction zone. The northern margin of the oceanic basin that is being consumed is formed by the pre-Middle Proterozoic North American craton, which is flanked by Lower Proterozoic greywacke turbidites (a) derived from Lower Proterozoic volcanic sequences found on the craton.* middle—*Middle Labradorian (ca. 1670 to 1630 Ma). Consumption of the oceanic basin results in: i) collision and accretion of the magmatic arc to the North American craton, ii) contraction, crustal thickening and high-grade metamorphism of the Lower Proterozoic sedimentary rocks (d) and thermal reworking of accreted rocks (f), iii) reversal of subduction polarity and formation of a continental magmatic arc represented by the Trans-Labrador batholith (e), and the ca. 1650 Ma Blueberry Lake group, iv) intrusion of the Ossok Mountain intrusive suite at middle to lower crustal levels.* bottom—*Late Labradorian (ca. 1630 to 1600 Ma). Intrusion of late syn- to posttectonic granitoid rocks (g). Possible collision (h) with terranes located to the south of the Labrador Orogen terminated subduction.*

provide the only evidence of pre-Grenvillian, post-Labradorian tectonothermal events in the Lac Joseph terrane. The ca. 1403 Ma ages slightly postdate Shabogamo–Michael magmatism, but may have some relationship to this event. In the Grenville Province of central Ontario, ca. 1280 Ma events are related to volcanism and deposition of the Grenville Supergroup and high-grade metamorphism of gneisses in the Central Gneiss Belt (Easton, 1986), and immediately precede the ca. 1250 to 1220 Ma plutonic events of the Elzevirian Orogeny (Moore and Thompson, 1980). The nature and significance of these thermal imprints on the Lac Joseph terrane are uncertain and more isotopic studies are required to more fully appreciate their regional importance.

GRENVILLIAN HISTORY

In the study area, the main effect of the Grenvillian Orogeny was the telescoping of nappes, defined as the Lac Joseph and Molson Lake terranes, against structurally lower, autochthonous, Early Proterozoic supracrustal rocks of the Gagnon terrane and the Laurentian craton. Although these nappes may share a similar Labradorian history, they represent significantly different levels of the Grenville Orogen. The Molson Lake terrane, is a structurally deeper level of the orogen that was metamorphosed and penetratively deformed at all scales in the Grenvillian. In contrast, the Lac Joseph terrane mainly escaped Grenvillian tectonothermal events and was apparently only metamorphosed in areas contiguous with the underlying nappe, attendant with the formation of Grenvillian, late syn-metamorphic high-strain zones along their mutual contact (JMBZ). This is consistent with U–Pb evidence that shows no indications of significant, regional Grenvillian heating of the Lac Joseph terrane. The absence of an extensive Grenvillian thermal imprint on the Lac Joseph terrane indicates medium- to high-pressure metamorphism of the Molson Lake terrane occurred prior to emplacement of the Lac Joseph terrane.

Thermobarometry of eclogitic rocks from the southwestern Molson Lake terrane indicates maximum Grenvillian pressures in excess of 15 kbar (Indares, 1993), and geochronological data allows for a period of approximately 10 to 15 Ma of exhumation following the metamorphic peak, prior to emplacement of the Lac Joseph terrane. These data constrain pre-juxtaposition uplift rates to be in the range from 2.5 to 5.0 km/m.y. for the Molson Lake terrane. Rapid uplift of the Molson Lake terrane is consistent with P-T-t paths proposed by Indares (1991) and by van Gool (1992) from the Gagnon terrane.

Grenvillian history of the Molson Lake terrane could be explained with a model (Figure 46) which predicts that rocks were buried to between 30 to 50 km by thrust nappes, consisting of Labradorian crust, and whose pre-Grenvillian position was between the Molson Lake terrane and the Lac Joseph terrane. These intervening rocks are a necessary ingredient in this model because the Lac Joseph terrane could not have been the principal tectonic load. Rapid erosion of the hanging-wall rocks occurred as hinterland-stepping

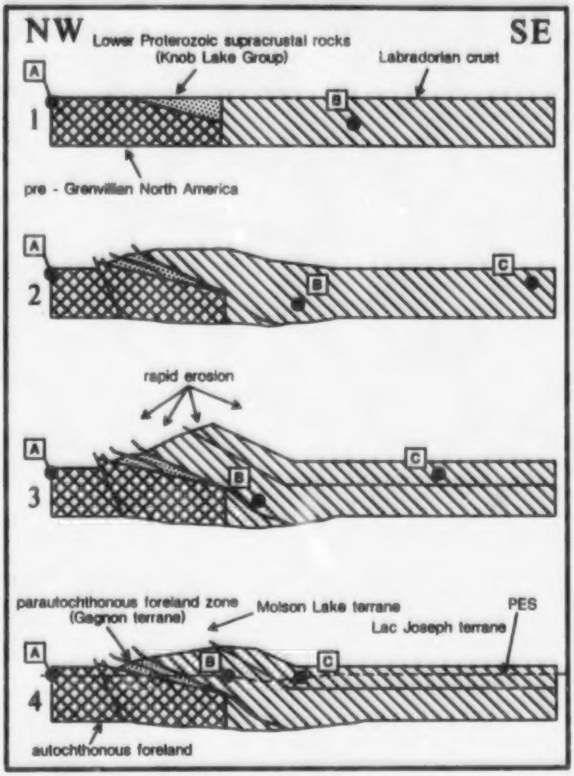


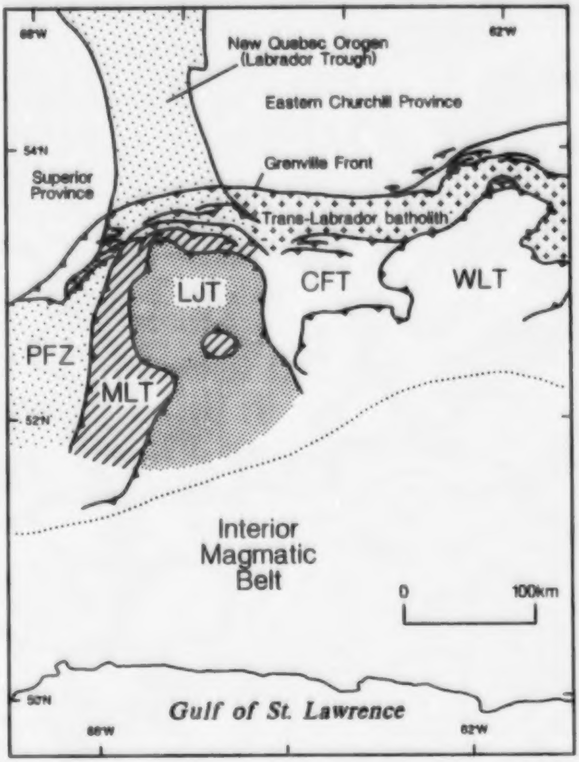
Figure 46. *Possible model for the Grenvillian history of the northeastern Grenville Province. 1–Pre-Grenvillian crustal configuration of northeastern Laurentia. Points A, B and C are three material points in the autochthon, Molson Lake and Lac Joseph terranes that will end up on the present erosion surface. 2–Grenvillian contraction results in crustal thickening, thrusting of Labradorian crust over the Knob Lake Group, formation of a mid-crustal level fold- and thrust-belt in the Knob Lake Group and formation or reactivation of faults in the autochthon. 3–Continued contraction and crustal thickening is balanced by rapid erosion. Point B goes through medium- to high-pressure metamorphism in the over-thickened crust. Thrusting steps farther back into the orogen and brings new material to the orogenic 'front' at a faster rate than rocks from the lower structural levels are being exhumed. 4–Termination of contraction, uplift and erosion to the present erosion surface (PES). The rocks represented by point C in the Lac Joseph terrane have mainly escaped Grenvillian thermal events and penetrative strain.*

thrusting brought nappes from farther south in the orogen. This thrusting, resulting in the addition of the Lac Joseph terrane to near the front of the orogen, balances the mass lost to rapid erosion of the exhumed lower nappe (the Molson Lake terrane) during a steady state, contractional Grenvillian Orogeny. This retrogressive thrusting model has been discussed by Connelly (1991), James and Connelly (1992) and James *et al.* (1992).

Alternatively, the JMBZ could be an extensional fault. In this model, extension is proposed to be related to tectonic collapse of an internal hinterland zone, which lies to the southeast of the Lac Joseph terrane, subsequent to regional contraction, granitic intrusion in the internal hinterland zone and the culmination of Grenvillian crustal thickening. A candidate for the internal hinterland zone is the Interior Magmatic Belt of Gower *et al.* (1991b) (Figure 47), inferred to consist of a significant proportion of voluminous, intermediate crustal-level Grenvillian granitic plutons. An extensional fault allows for the Lac Joseph terrane, a structurally higher level of the Grenville Orogen, to be juxtaposed against the structurally deeper Molson Lake terrane. Emplacement of the Lac Joseph terrane, from the southeast, onto the underlying rocks in an extensional regime might also explain the absence of regionally pervasive syn-juxtaposition, Grenvillian contractional structures in the Lac Joseph terrane. Mapping of areas south of the present study area is required to test this model. An extensional model for the Lac Joseph terrane has been presented by Rivers *et al.* (1991).

As pointed out by Rivers and Nunn (1985), Connelly and Nunn (1988), and Rivers *et al.* (1991) there are lithologic linkages between the Grenvillian terranes and the pre-Grenvillian North American craton in western Labrador. These linkages include: 1) the Lower Proterozoic supracrustal rocks (Knob Lake Group), which occur in the autochthonous pre-Grenvillian Laurentian craton and in the Gagnon terrane, 2) Shabogamo Gabbro, which occurs in the Gagnon terrane, and in the Molson Lake and Churchill Falls terranes, 3) Trans-Labrador batholith and related Labradorian intrusions, which occur in the Churchill Falls and Molson Lake terranes and in the Lac Joseph terrane, and 4) Labradorian paragneiss, which occurs in the Churchill Falls and Lac Joseph terranes. The model presented in Figure 46 predicts that there is some missing crust between the Molson Lake and Lac Joseph terranes, although these fundamental linkages demonstrate that there is a need for a review of how the terms terrane, allochthonous and parautochthonous are used in western Labrador.

In the case of the Molson Lake and Churchill Falls terranes, the lithologic linkages, similarities in Labradorian intrusive history and Grenvillian tectonothermal history, and the absence of a demonstrable tectonic break between the two, suggests that these two geographic parts of the same tectonic unit should not be named separately. Perhaps the term Churchill Falls terrane should be dropped (partly because the town of Churchill Falls is not in the Churchill Falls terrane), and the name Molson Lake terrane be given to the entire tectonic slice that underlies the Lac Joseph terrane. Admittedly, there are orogen-parallel lithologic variations in this expanded Molson Lake terrane (e.g., the preponderance of granitoid rocks in the southwestern part of the terrane), and there may be some Grenvillian metamorphic variations over this same area (e.g., differences in Grenvillian paleopressure), but if these are deemed to be significant, a subdivision of the Molson Lake terrane into lithologic, or metamorphic, or structural domains is preferable over naming new terranes. Determination of the exact relationship between



PFZ - Parautochthonous Foreland Zone

MLT - Molson Lake Terrane

LJT - Lac Joseph Terrane

CFT - Churchill Falls Terrane

WLT - Wilson Lake Terrane

Figure 47. *Principal tectonic elements of the northeastern Grenville Province (modified after Gower* et al., *1991b).*

the Molson lake and Churchill Falls terranes, and resolving the internal structure of each, remain outstanding regional problems.

The Molson Lake and Lac Joseph terranes are fault bounded tectonic units, although in some cases the faults do not juxtapose dissimilar rocks, and neither of these terranes can be unequivocally demonstrated to be foreign to the pre-Grenvillian North American craton. Separating these two Grenvillian nappes from the North American craton is the Gagnon terrane, which is not fault bounded. Accordingly, the Gagnon, Molson Lake and Lac Joseph terranes should be thought of as essentially in situ tectonic units that have genetic links to the craton and to each other. Hence, the terms terrane and allochthonous terrane are perhaps inappropriate, specifically in reference to the Lac Joseph terrane (see discussions in Dover, 1990, and Sengör and Dewey, 1990). To avoid the contentious terranology issue in the future, the genetic terms nappe or deck could be applied to the Molson Lake and Lac Joseph terranes (e.g., Lac Joseph nappe), and parautochthonous foreland zone given to the Gagnon terrane.

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REFERENCES

Anders, E. and Ebihara, M.
1982: Solar system abundances of the elements, Geochimica et Cosmochimica Acta, Volume 46, pages 2363-2380.

Ashton, K.E. and Leclair, A.D.
1990: Foliate: a useful term to compliment the textural classification of foliated metamorphic rocks. Canadian Journal of Earth Sciences, Volume 27, pages 1095-1097.

Ashwal, L.D., Wooden, J.L. and Emslie, R.F.
1986: Sr, Nd, and Pb isotopes in Proterozoic intrusives astride the Grenville Front in Labrador: Implications for crustal contamination and basement mapping. Geochimica et Cosmochimica Acta, Volume 50, pages 2571-2585.

Brooks, C.
1983: Fourth report on the geochronology of Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File [Lab 519], 32 pages.

Carmichael, D.M.
1978: Metamorphic bathozones and bathograds: a measure of the depth of post-metamorphic uplift and erosion on the regional scale. American Journal of Science, Volume 278, pages 769-797.

Connelly, J.N.
1988: An investigation of the margin of the Lac Joseph Allochthon, Grenville Province, southwestern Labrador. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 37-48.

1991: The thermotectonic history of the Grenville Province in western Labrador. Ph.D. Thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 316 pages.

1992: U–Pb geochronological research agreement: final report for the Newfoundland Department of Mines and Energy, Labrador Mapping Section, unpublished report, 112 pages.

Connelly J.N. and Heaman, L.M.
1993: Constraints on the tectonic evolution of the Grenville Province, western Labrador, from U–Pb geochronology. Precambrian Research 1994, pages 123-142.

Connelly, J.N. and Nunn, G.A.G.
1988: Relationships between the Lac Joseph Allochthon and underlying terranes, southwestern Labrador. Geological Association of Canada–Mineralogical Association of Canada–Canadian Society of Petroleum Geologists, Annual Meeting, Program with Abstracts, Volume 13, page A24.

Connelly, J.N. and Scowen, P.
1987: Geology of the Lac Caopacho-Lac Fleur-de-May area, southwestern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 225-235.

Connelly, J.N., Heaman, L. and Krogh, T.E.
1990: U–Pb geochronology and the evolution of the Grenville Province of western Labrador. Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, Volume 15, page A26.

Connelly, J.N., van Gool, J. and Rivers, T.
1989: Molson Lake Terrane, a new terrane in the parautochthonous belt of the Grenville Province in southwestern Labrador. Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, Volume 14, page A23.

Currie, K.L. and Loveridge, W.D.
1985: Geochronology of retrogressed granulites from Wilson Lake, Labrador. *In* Current Research, Part B. Geological Survey of Canada, Paper 85-1B, pages 191-197.

Davis, D.W.
1982: Optimum linear regression and error estimation applied to U–Pb data. Canadian Journal of Earth Sciences, Volume 19, pages 2141-2149.

Dover, J.H.
1990: Opinion: Problems of terrane terminology—causes and effects. Geology, Volume 18, pages 541-544.

Easton, R.M.
1986: Geochronology of the Grenville Province; Part I: Compliation of data; Part II: Synthesis and interpretation. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 127-174.

Emslie, R.F., Hulbert, L.J., Brett, C.P. and Garson, D.F.
1978: Geology of the Red Wine Mountains, Labrador: the Ptarmigan Complex. *In* Current Research, Part A. Geological Survey of Canada, Paper 78-1A, pages 129-134.

Evensen, N.M., Hamilton, P.J. and O'Nions, R.K.
1978: Rare-earth abundances in chondritic meteorites. Geochimica et Cosmochimica Acta, Volume 42, pages 1199-1212.

Fahrig, W.F.
1967: Shabogamo Lake map area (east half), Newfoundland—Labrador and Quebec. Geological Survey of Canada, Memoir 354, 23 pages.

Fahrig, W.F. and Larochelle, A.
1972: Paleomagnetism of the Michael Gabbro and possible evidence of the rotation of the Makkovik Subprovince. Canadian Journal of Earth Sciences, Volume 9, pages 1287-1296.

Frarey, M.J. and Duffell, S.
1964: Revised stratigraphic nomenclature for the central part of the Labrador Trough. Geological Survey of Canada, Paper 64-25, 13 pages.

Fryer, B.J.
1983: Report on geochronology—Labrador mapping: unpublished summary of geochronological results obtained on samples collected from central Labrador between 1978 and 1980. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File LAB (617), 35 pages.

Gower, C.F. and Owen, V.
1984: Pre-Grenvillian and Grenvillian litotectonic regions in eastern Labrador—correlations with the Sveconorwegian Orogenic Belt in Sweden. Canadian Journal of Earth Sciences, Volume 21, pages 678-693.

Gower, C.F., Rivers, T. and Brewer, T.S.
1991a: Middle Proterozoic mafic magmatism in Labrador, eastern Canada. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada, Special Paper 38, pages 485-506.

Gower, C.F., Heaman, L.M., Loveridge, W.D., Schärer, U., and Tucker, R.D.
1991b: Grenvillian magmatisim in the eastern Grenville Province, Canada. Precambrian Research, Volume 51, pages 315-336.

Gower, C.F., Schärer, U., and Heaman, L.M.
1992: The Labradorian orogeny in the Grenville Province, eastern Labrador, Canada. Canadian Journal of Earth Sciences, Volume 29, pages 1944-1957.

Indares, A.
1991: Eclogitized metagabbros related to the allochthonous boundary thrust of the eastern Grenville Province. Geological Association of Canada—Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, Volume 16, page A59.

1993: Eclogitized gabbros from the eastern Grenville Province: textures, metamorphic context, and implications. Canadian Journal of Earth Sciences, Volume 30, pages 159-173.

Irvine, T.N. and Baragar, W.R.A.
1971: A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences, Volume 8, pages 523-548.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C. and Essling, A.M.
1971: Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U. Physical Review, Section C: Nuclear Physics, Volume 4, pages 1889-1906.

James, D.T.
1991: Geology of the Ossokmanuan Lake (23H/SW)—Lac Joseph (23A/NW) area, Labrador. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File Map 91-85.

James, D.T and Connelly, J.N.
1992: Assembly of the Grenville Province, western Labrador. Friends of the Grenville Workshop, Quebec City, April 1992, Program and Abstracts.

James, D.T., Dunphy, D.G. and Stephenson, D.M.
1990: Preliminary report on geological mapping in the Ossokmanuan Lake—Lac Joseph area, Grenville Province, western Labrador. *In* Report of Activites. Newfoundland Department of Mines and Energy, Geological Survey Branch, pages 3-7.

1991: The Lac Joseph Terrane and the Churchill Falls Terrane: structural and metamorphic relations, Ossokmanuam Lake (NTS 23H/SW) and Lac Joseph (NTS 23A/NW) map areas, Grenville Province, western Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 217-227.

James, D.T., Connelly, J.N., and van Gool, J.
1992: A foreland to hinterland transect across the Grenville Front: a western Labrador perspective. *In* Eastern Canadian Shield onshore-offshore transect (ECSOOT), Report of 1992 transect meeting. *Edited by* R.J. Wardle and J. Hall. The University of British Columbia, LITHOPROBE Secretariat, Report No. 32, pages 201-205.

Jenner, G.A., Longerich, H.P., Jackson, S.E. and Fryer, B.J.
1990: ICP-MS—a powerful tool for high precision trace element analysis in earth sciences: evidence from analysis of selected USGS reference samples. Chemical Geology, Volume 83, pages 133-148.

Kerr, A.
1989a: Geochemistry of the Trans-Labrador granitoid belt, Canada: A quantitative comparative study of a Proterozoic batholith and possible Phanerozoic counterparts. Precambrian Research, Volume 45, pages 1-17.

1989b: Early Proterozoic granitoid magmatism and crustal evolution in the Makkovic Province of Labrador: a geochemical and isotopic study. Ph. D. thesis, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, 528 pages.

Kerr, A., Fryer, B.J. and Wardle, R.J.
1992: Nd isotopic studies in the Labrador shield: a progress report and preliminary results. *In* Eastern Canadian Shield onshore-offshore transect (ECSOOT), Report of 1992 transect meeting. *Edited by* R.J. Wardle and J. Hall. The University of British Columbia, LITHOPROBE Secretariat, Report No. 32, pages 179-182.

Krogh, T.E.
1983: Report on U-Pb sphene geochronology, Labrador and Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File [Lab 708], 79 pages.

Longerich, H.P., Jenner, G.A., Fryer, B.J. and Jackson, S.E.
1990: Inductively coupled plasma-mass spectrometric analysis of geological samples: a critical evaluation based on case studies. Chemical Geology, Volume 83, pages 105-118.

Mattauer, M.
1975: Sur le mechanisme de formation de la schistosité dans l'Himalaya. Earth and Planetary Science Letters, Volume 28, pages 144-154.

Mattauer, M., Collot, B. and Van den Driessche, J.
1983: Alpine model for the internal metamorphic zones of the North American Cordillera. Geology, Volume 11, pages 11-15.

Meschede, M.
1986: A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Mb-Zr-Y diagrams. Chemical Geology, Volume 56, pages 207-218.

Meyer, J.
1989: Graphite, mica and heavy-mineral sands exploration in Labrador. *In* Report of Activities. Newfoundland Department of Mines and Energy, Geological Survey Branch, pages 11-12.

Moore, J.M. and Thompson, P.H.
1980: The Flinton Group: a late Precambrian metasedimentary succession in the Grenville Province of eastern Ontario. Canadian Journal of Earth Sciences, Volume 17, pages 1685-1707.

Newfoundland Department of Mines and Energy
1976: Mineral Occurrence Tables, Labrador, Open File: Lab 326, 94 pages, (accompanies Mineral Occurrence Map of Labrador, Map 761).

Nunn, G.A.G.
1990: Geology of the Julian River map area, 23H/SE. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File Map.

Nunn, G.A.G. and Christopher, A.
1983: Geology of the Atikonak River area, Grenville Province, western Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 83-1A, pages 363-370.

Nunn, G.A.G., Noel, N. and Culshaw, N.G.
1984: Geology of the Atikonak Lake area, Grenville Province, western Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 30-41.

Nunn, G.A.G., Thomas, A. and Krogh, T.E.
1985: The Labradorian Orogeny: geochronclogical data base. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 43-54.

Pattison, D. and Tracy, T.
1991: Phase equilibria and thermobarometry of metapelites. Mineralogical Society of America, Reviews in Mineralogy, Volume 26, pages 105-206.

Pearce, J.A. and Cann, J.R.
1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters, Volume 19, pages 290-300.

Philippe, S., Wardle, R.J. and Schärer, U.
1993: Labradorian and Grenvillian crustal evolution of the Goose Bay region, Labrador: new U–Pb geochronological constraints. Canadian Journal of Earth Sciences, Volume 30, pages 2315-2327.

Ramsay, J.G.
1967: Folding and fracturing of rocks. McGraw-Hill, Toronto, 568 pages.

Rivers, T.
1980: Revised stratigraphic nomenclature for Aphebian and other rock units, southern Labrador Trough, Grenville Province. Canadian Journal of Earth Sciences, Volume 17, pages 668-670.

1983: The northern margin of the Grenville Province in western Labrador—anatomy of an ancient orogenic front. Precambrian Research, Volume 22, pages 41-73.

1985a: Geology of the Opocopa Lake area, Labrador–Quebec. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-24.

1985b: Geology of the Gabbro Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-26.

1985c: Geology of the Wightman Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-28.

Rivers, T. and Chown, E.H.
1986: The Grenville Orogen in eastern Quebec and western Labrador—definition, identification and tectonometamorphic relationships of autochthonous, parautochthonous and allochthonous terranes. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 30-50.

Rivers, T., Connelly, J.N., van Gool, J. and Brown, D.
1991: Anatomy of a crustal-scale thrust stack in the Grenville orogen of western Labrador—a synopsis. Geological Association of Canada—Mineralogical Association of Canada, Joint Annual Meeting, Program with Abstracts, Volume 16, page A106.

Rivers, T. and Mengel, F.C.
1988: Contrasting assemblages and petrogenetic evolution of corona and noncorona gabbros in the Grenville Province of western Labrador. Canadian Journal of Earth Sciences, Volume 25, pages 1629-1648.

Rivers, T. and Nunn, G.A.G.
1985: A reassessment of the Grenvillian Orogeny in eastern Quebec and western Labrador. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. Reidel Publishing, NATO Advanced Science Institute Series, Volume 158, pages 163-174.

Rivers, T., Martignole, J., Gower, C.F. and Davidson, A.
1989: New tectonic divisions of the Grenville Province, southeast Canadian Shield. Tectonics, Volume 8, pages 63-84.

Ryan, B.
1984: Regional geology of the central part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 3, 185 pages.

Schärer, U., Krogh, T.E. and Gower, C.F.
1986: Age and evolution of the Grenville Province in eastern Labrador from U–Pb systematics in accessory minerals. Contributions to Mineralogy and Petrology, Volume 94, pages 438-451.

Sengör, A.M.C. and Dewey, J.F.
1991: Terranology: vice or virtue. *In* Allochthonous Terranes. *Edited by* J.F. Dewey, I.G. Gass, G.B. Curry, N.B.W. Harris and A.M.C. Sengör. Cambridge University Press, Cambridge, pages 1-22.

Stevenson, I.M.
1967: Geology of the Lac Joseph map area (23A), Newfoundland and Quebec. Geological Survey of Canada Paper 67-62, 4 pages.

1970: Rigolet and Groswater Bay map areas, Newfoundland (Labrador) (13J, 13I). Geological Survey of Canada, Paper 69-48, 24 pages.

Swinden, H.S., Wardle, R.J., Davenport, P.H., Gower, C.F., Kerr, A., Meyer, J.R., Miller, R.R., Nolan, L., Ryan, A.B. and Wilton, D.H.C.
1991: Mineral exploration opportunities in Labrador—a perspective for the 1990's. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 349-390.

Taylor, S.R. and McLennan, S.M.
1985: The Continental Crust: its composition and evolution. Blackwell, Oxford, 312 pages.

Thomas, A.
1981: Geology along the southwestern margin of the Central Mineral Belt. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-4, 40 pages.

Thomas, A. and Blomberg, P.
1990: Geology of the Grenville Province crystalline rocks in the region between Wilson and Winokapau lakes (NTS 13E/1, 13E/2, 13E/7 and 13E/8), south-central Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 251-266.

Thomas, A., Jackson, V. and Finn, G.
1983: Geology, Mountainer Lakes–East Red Wine Mountains area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 83-33.

Thomas, A., Nunn, G.A.G. and Krogh, T.E.
1986: The Labradorian Orogeny: Evidence for a newly identified 1600-1700 Ma orogenic event in Grenville Province crystalline rocks from central Labrador. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 13-29.

Thomas, A., Nunn, G.A.G. and Wardle, R.J.
1985: A 1650 Ma orogenic belt within the Grenville Province of northeastern Canada. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. Reidel Publishing, NATO Advanced Science Institute Series, Volume 158, pages 151-161.

van Gool, J.
1992: The Grenville Front foreland fold-and-thrust belt in southwestern Labrador: mid-crustal structural and metamorphic configuration of a Proterozoic orogenic thrust wedge. Ph.D. Thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 428 pages.

Wardle, R.J.
1985: Geology of the Churchill Falls area. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-2, 70 pages.

Wardle, R.J., Crisby-Whittle, L.V.J. and Blomberg, P.
1990: Geology of the Minipi River area (NTS 13C/NW). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 267-276.

Wardle, R.J., Rivers, T., Gower, C.F., Nunn, G.A.G. and Thomas, A.
1986: The northeastern Grenville Province: new insights. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 13-29.

Wardle, R.J., Ryan, B., Philippe, S. and Schärer, U.
1991: Proterozoic crustal development, Goose Bay region, Grenville Province, Labrador, Canada. *In* Mid-Proterozoic Laurentia-Baltica. *Edited by* C.F. Gower, T. Rivers and B. Ryan. Geological Association of Canada, Special Paper 38, pages 197-214.

Winchester, J.A. and Floyd, P.A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, Volume 20, pages 325-343.

Windley, B.F.
1981: Phanerozoic granulites. Geological Society of London, Volume 138, pages 745-751.

Wood, D.A.
1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province. Earth and Planetary Science Letters, Volume 50, pages 11-30.

Wynne-Edwards, H.R.
1961: Geology of Ossokmanuan Lake (West Half), Newfoundland. Geological Survey of Canada, Map 17-1961.

Note: Geological Survey Branch file numbers are given in square brackets.

APPENDIX 1

GEOCHRONOLOGICAL DATA

Appendix 1 contains U–Pb isotopic data and geochronological interpretations for samples of granitoid gneiss (DJ-90-2297), Ossok Mountain intrusive suite (DJ-90-10) and Shabogamo Gabbro (DJ-90-2303) from the study area. The data were collected at the Department of Earth Sciences, Memorial University of Newfoundland, by Dr. James N. Connelly. The results presented here were first reported in March 1992, in the final report of the U–Pb geochronological research agreement between Memorial University and the Newfoundland Department of Mines and Energy (Connelly, 1992). The following short description of the analytical procedure and the interpretations of the data are reproduced from that report.

General Procedures

The rock samples were crushed and minerals suitable for geochronology were separated under clean conditions using a rock crusher, Wilfley panning table, Frantz magnetic separator, sieves and heavy liquids. Final magnetic separation yielded a series of mineral splits of variable quality because the magnetic properties of these minerals are a function of the degree of alteration. Zircon, monazite, titanite, baddeleyite and rutile fractions were selected for analysis on the basis of microscopic optical properties to ensure that only the highest quality grains were analyzed. To limit the effect of Pb loss due to alteration, the outer surfaces of most fractions were removed by abrasion.

The best grains after abrasion were washed in distilled nitric acid, water and finally acetone. The fractions were weighed into TEFLON capsules with a mixed $^{205}Pb-^{235}U$ isotopic tracer and Hf and HNO_3 acid for dissolution (monazite with HCl). Zircon, baddeleyite and rutile dissolution was carried out in an oven at 210°C over 5 days. Monazite and titanite dissolution was carried out on a hot plate. Low-blank ion exchange chemistry was carried out, using miniaturized columns for the zircon, baddeleyite and rutile fractions and small columns for monazite and titanite. Total procedure blanks were in the range 4 to 15 picograms common Pb for zircon chemistry and ca. 25 picograms for monazite and titanite during this time. Additional common Pb in the analyses reported was likely present in the grains, incorporated at the time of crystallization.

Pb and U were loaded together on silica gel with phosphoric acid onto an outgassed rhenium ribbon. The isotopic compositions of Pb and U were measured on a multi-collector MAT 262 thermal ionization mass spectrometer, typically operating in static mode with ^{204}Pb measured in the axial SEM/ion counter. Small samples were measured in peak jumping mode in the axial SEM/ion counter. Ages were calculated using the accepted decay constants of Jaffey *et al.* (1971). Errors on the isotopic ratios were calculated by propagating uncertainties in measurement of isotopic ratios, fractionation and amount of blank with a program modified after an unpublished error propogation program written by L. Heaman. Linear regressions were calculated using the procedure of Davis (1982). Table A1-1 contains the isotopic data.

Table A1-1. Isotopic age data

Fraction	Weight (mg)	Concentration U (ppm)	Concentration Pb rad (ppm)	Measured total common Pb (pg)	Measured $^{206}Pb/^{204}Pb$	Corrected Atomic Ratios * $^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$		$^{207}Pb/^{235}U$		$^{207}Pb/^{206}Pb$		Age (Ma) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
DJ-90-10: OSSOKMANUAN GABBRO															
Z1 sm-med grains	0.026	381	140.4	64	2808	0.3842	0.28811	141	3.9977	189	0.10064	18	1632	1634	1636
Z4 elongate with facets	0.077	154	55.9	4	52060	0.3709	0.28719	55	3.9955	80	0.10090	6	1627	1633	1641
Z5 lg frags; best	0.060	243	85.9	9	28443	0.3304	0.28705	50	3.9900	74	0.10081	5	1627	1632	1639
R1 best rutile	0.044	381	105.4	13	24161	0.0156	0.28796	114	4.0011	160	0.10077	6	1631	1634	1638
DJ-90-2297: LAC JOSEPH TERRANE GRANITOID															
T1 lg brown fragments	0.301	261	54.1	923	956	0.2869	0.17644	163	1.8553	173	0.07626	6	1048	1065	1102
T2 dark brown xls	0.209	487	77.0	2028	544	0.0242	0.16778	34	1.6746	40	0.07239	7	1000	999	997
T3 light yellow frags	0.089	84	14.5	344	258	0.0647	0.17562	86	1.8313	102	0.07563	24	1043	1057	1085
T4 light brown frags	0.099	342	71.7	261	1505	0.2464	0.18369	93	1.9916	101	0.07863	8	1087	1113	1163
DJ-90-2303: GABBRO BODY AROUND LAC JOSEPH															
B1 best badd	0.028	259	60.1	104	1100	0.0163	0.24400	50	3.0293	68	0.09004	11	1407	1415	1426
B2 badd w. zirc rasp	0.051	294	62.4	19	10846	0.0720	0.21351	38	2.4960	46	0.08478	6	1247	1271	1311
B3 badd w. zirc rasp	0.050	208	43.0	13	10489	0.0339	0.214[illegible]	66	2.5143	74	0.08493	11	1254	1276	1314
B4 badd xls	0.011	380	88.7	10	6329	0.0062	0.24762	121	3.0891	144	0.09048	15	1426	1430	1436

NOTE: * Corrected for fractionation, spike, laboratory Pb blank of 5 to 25 pg and initial common Pb at the time of mineral crystallization calculated from the model of Stacey and Kramers (1975), and 2 pg U blank. Two sigma uncertainties on isotopic ratios, calculated with a modified, unpublished error propagation program written by L. Heaman, are reported after the ratios and refer to the final digits.

Abbreviations: frags–fragments; lg–large; med–medium; sm–small; xls–crystals; w.–with; rasp–raspberries; badd–baddeleyite; zirc–zircon
Code in fraction numbers: B = baddeleyite; M = monazite; R = Rutile; T = titanite; Z = zircon

DJ-90-2297: Granitoid gneiss

A hand sample was processed in order to isolate titanite, observed in abundance in thin section, and zircon. Four fractions of titanite were selected from the magnetic split at 10°/1.7 amp. All titanite fractions were clear, free of inclusions, and varied in colour from light yellow to dark brown; grains ranged from fragments to flat, faceted crystals. All fractions were lightly abraded.

The four titanite fractions and two zircon fractions define a mixing line between 1001 $\pm$ 7 Ma and 1660 $\pm$ 5 Ma with an 86 percent probablity of fit (Figure 6). The lower intercept age represents the time of Grenvillian-aged metamorphism and indicates that temperatures were compatible with new titanite growth. This result represents the first direct U−Pb evidence of new mineral growth in the Lac Joseph Terrane during the Grenvillian Orogeny.

The zircon fractions constrain the upper intercept, and indicate that this body was emplaced during the early Labradorian Orogeny.

DJ-90-10: Ossok Mountain Intrusive Suite

A 20 kg sample of coarse-grained gabbro yielded euhedral crystals and fragments of zircon and rutile. All fractions of zircon were selected from the non-magnetic split at 0°/1.7 amps, except Z5, which came from the magnetic split at 1°/1.7 amps; all zircon analyzed were clear, colourless and virtually free of inclusions. Rutile was selected from splits at 1,3 and 5°/1.7 amps and combined into a single fraction representing the best grains. Zircon and rutile were both abraded. Common Pb in all analyses from this rock ranged between 4 and 63 picograms. All fractions were either concordant or with 1 percent of concordia.

The $^{207}Pb/^{206}Pb$ ages for zircon and rutile vary between 1636 and 1641 Ma (Figure 8) with no evidence for isotopic resetting of U-Pb systematics during the Grenvillian Orogeny. Rutile overlapping the zircon analyses implies that temperatures during the Grenvillian Orogeny were below the former's blocking temperature (estimated to be about 400°C). With no justification for a mixing line to pass through 1000 Ma, these points have been regressed through the origin and yield an upper intercept of 1639 $\pm$ 2 Ma. This age is interpreted to represent the igneous crystallization age.

DJ-90-2303: Shabogamo Gabbro

Two 'monoliths' of gabbro (approximately 40 kg total) yielded euhedral, dark-brown baddeleyite and baddeleyite grains rimmed by 'raspberry' zircon. Baddeleyite crystals and baddeleyite with zircon were selected from splits at 0° to 3°/1.7 amp and combined to make two fractions of each. The baddeleyite grains represent the clearest gems but some inclusions were unavoidable in order to obtain reasonable fraction sizes; both fractions of baddeleyite crystals were abraded lightly. Zircon raspberries around baddeleyite obscured the quality of the later mineral thus rendering optical selection difficult. The baddeleyite cores in the selected grains contained longitudinal fractures and colour banding. Assuming the zircon was a secondary overgrowth, fraction B2 was not abraded so that the zircon component would move the point as close to the age of overgrowth as possible. Fraction B3 was abraded in an attempt to remove some of the zircon overgrowth.

The four points define a mixing line with an upper intercept at 1452 $^{+15}_{-13}$ Ma and a lower intercept of 966 $\pm$ 30 Ma (Figure 9). The baddeleyite crystals are 5.6 percent and 9.6 percent discordant while the baddeleyite with overgrowths are 41.8 percent and 43.1 percent discordant. The upper intercept age indicates the igneous crystallization age. The lower intercept age indicates that a metamorphic event at 966 $\pm$ 30 Ma results in zircon crystallization around pre-existing baddeleyite. This age, with a large error, indicates that this gabbro body, situated in the central part of the Lac Joseph Terrane, was affected by Grenvillian-aged mineral recrystallization. The crystallization age is coincidental (within error) with the 1459 $^{+23}_{-22}$ Ma age obtained from the Shabogamo Intrusive Suite, sampled to the east of Labrador City (Connelly and Heaman, 1993) and is therefore correlated with this suite.

APPENDIX 2

GEOCHEMICAL DATA

Appendix 2 contains major-, trace-, and rare earth-element chemical data for samples of Ossok Mountain intrusive suite and Shabogamo Gabbro. Sample numbers are listed in Table A2-1 and data is contained in Tables A2-2 and A2-3.

Table A2-1. Sample numbers

Field Number	Sample Number	Field Number	Sample Number
DJ-90-2054	1	DJ-90-2392	13
DJ-90-2067	2	DJ-90-2388	14
DJ-90-2403	3	DJ-90-2385	15
DJ-90-2070	4	DJ-90-1195	16
DJ-90-2083	5	DJ-90-2146	17
DJ-90-2196	6	DJ-90-2354	18
DJ-90-2012	7	DJ-90-2363	19
DJ-90-2028	8	DJ-90-2368	20
DJ-90-3055	9	DJ-90-2302	21
DJ-90-2016	10	DJ-90-2324	22
DJ-90-0008	11	DJ-90-2334	23
DJ-90-2027	12		

Samples 1-12 are from the Ossok Mountain intrusive suite.
Samples 13-23 are from the Shabogamo Gabbro. Samples 21 to 23 are from the tectonic window at Lac Joseph.

Table A2-2. Major-element chemistry of the Ossok Mountain intrusive suite and the Shabogamo Gabbro

SAMPLE	UNIT	SiO_2	Al_2O_3	TOTAL† Fe	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	TOTAL
01	OM	53.95	16.64	8.69	1.36	6.59	4.87	8.43	3.10	1.92	0.86	0.14	0.18	0.94	98.98
02	OM	50.75	15.65	11.93	1.61	9.29	6.64	9.09	2.62	1.32	1.36	0.18	0.26	1.11	99.88
03	OM	51.25	19.03	7.92	0.82	6.39	8.92	9.26	2.48	0.29	0.34	0.13	0.02	0.82	99.75
04	OM	53.30	18.70	8.20	3.06	4.63	6.96	7.75	3.38	0.75	0.62	0.17	0.17	0.94	100.43
05	OM	48.95	21.06	8.68	2.63	5.44	9.25	9.24	1.79	0.25	0.71	0.18	0.04	0.67	100.21
06	OM	50.20	18.94	9.93	3.23	6.03	5.71	9.66	3.19	0.35	1.12	0.15	0.35	0.88	99.81
07	OM	48.65	16.35	13.74	4.81	8.04	7.48	9.15	2.44	0.40	1.23	0.20	0.04	0.93	99.71
08	OM	51.75	16.09	9.99	4.60	4.86	6.68	8.54	3.25	1.20	1.03	0.16	0.55	0.70	99.41
09	OM	48.05	18.70	8.96	2.89	5.46	10.54	10.78	2.11	0.24	0.27	0.13	0.01	0.89	100.07
09 *	OM	48.10	21.24	8.85	2.39	5.82	7.03	9.95	3.28	0.43	0.66	0.11	0.10	0.98	100.09
10	OM	46.85	20.19	10.14	3.46	6.01	10.69	9.79	1.83	0.33	0.31	0.13	0.04	0.84	100.47
11	OM	48.45	18.43	8.10	2.60	4.95	11.89	11.41	1.66	0.18	0.24	0.13	0.03	0.63	100.60
12	OM	45.25	15.97	10.21	2.85	6.63	17.01	9.11	1.55	0.17	0.28	0.14	0.03	0.95	99.94
13	SH	48.85	17.56	10.41	2.14	7.44	7.45	9.25	2.43	1.11	1.09	0.16	0.26	0.91	98.65
14	SH	50.15	15.90	12.49	3.35	8.23	6.96	8.52	2.56	4.26	1.26	0.20	0.33	0.99	99.70
15	SH	54.10	15.29	11.57	2.98	7.73	4.60	7.34	3.03	2.43	1.29	0.20	0.33	0.98	100.30
16	SH	50.10	15.26	12.84	3.21	8.67	6.27	8.78	2.71	1.56	1.63	0.20	0.46	1.13	99.98
17	SH	47.10	22.02	6.54	0.43	5.50	11.10	10.61	2.24	0.17	0.24	0.08	0.06	1.03	100.58
18	SH	49.60	14.38	13.78	3.13	9.59	6.85	9.35	2.68	0.91	1.91	0.20	0.31	1.00	99.91
19	SH	45.85	16.89	15.93	3.84	10.88	6.67	7.76	3.05	1.00	2.98	0.19	0.53	1.07	100.71
20	SH	48.15	17.46	12.74	2.57	9.15	7.20	8.99	2.93	0.67	1.78	0.17	0.34	1.24	100.65
21	SH	48.65	21.01	8.59	2.15	5.79	7.24	9.81	3.23	0.42	0.67	0.12	0.11	0.79	99.99
22	SH	48.50	18.73	11.06	3.39	6.90	8.44	8.41	3.05	0.76	1.23	0.14	0.32	0.81	100.68
23	SH	48.95	20.97	8.84	1.86	6.28	6.47	9.09	3.46	0.64	1.03	0.11	0.26	0.76	99.88
MRG-1	standard	65.55	14.55	3.67			2.24	2.42	3.71	4.55	0.66	0.05	0.29		97.69
Ossok mean		49.65	18.23	9.64	2.79	6.16	8.74	9.40	2.51	0.60	0.69	0.15	0.14	0.87	
std. dev.		2.41	1.86	1.60	1.10	1.25	3.11	0.93	0.65	0.52	0.38	0.03	0.16	0.13	
Shabogamo mean		49.09	17.77	11.34	2.64	7.83	7.20	8.90	2.85	1.27	1.37	0.16	0.30	0.97	
std. dev.		1.95	2.35	2.35	0.79	1.66	2.95	1.04	0.58	1.03	0.74	0.04	0.16	0.15	
SH *		49.18	16.83			11.37	7.99	8.45	2.81	1.04	1.76	0.17	0.40		
std. dev.		3.47	2.61			2.05	3.41	1.20	0.44	0.85	0.82	0.04	0.34		
MG *		47.55	16.92			13.05	7.61	8.55	2.83	0.99	1.91	0.18	0.41		
std. dev.		1.77	2.88			2.62	3.32	1.27	0.48	0.50	0.74	0.04	0.23		

Sample 09 * is a duplicate analysis of sample 9. †Total Fe is total Fe as Fe_2O_3.

The values of SH * and MG * are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower *et al.* (1991a).

Table A2-3. Trace- and rare earth-element chemistry of the Ossok Mountain intrusive suite and the Shabogamo Gabbro

SAMPLE	UNIT	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd 157	Gd 160	Tb	Dy
01	OM	622	15.1	107	6.7	649	21.7	45.7	5.4	20.5	3.9	1.12	3.43	3.44	0.46	2.59
02	OM	252	27.5	161	6.6	487	20.6	44.9	5.5	22.1	4.8	1.39	5.58	5.39	0.74	5.19
03	OM	435	3.8	10	0.3	161	2.0	4.7	0.4	2.1	0.4	0.36	0.59	0.50	0.09	0.64
04	OM	766	12.6	22	5.8	312	27.1	52.6	5.9	23.1	4.1	1.19	3.88	3.24	0.44	2.50
05	OM	369	6.9	56	1.8	226	14.5	26.5	2.8	10.3	1.6	0.69	1.50	1.35	0.18	1.05
06	OM	803	10.6	80	5.7	317	14.8	33.6	4.4	19.2	3.7	1.24	2.88	3.03	0.36	1.97
07	OM	518	8.2	19	0.9	393	3.9	8.0	1.1	5.0	1.4	0.80	1.66	1.53	0.23	1.48
08	OM	1274	13.8	54	4.8	956	34.0	74.6	9.4	37.2	6.4	1.71	4.54	4.42	0.50	2.82
09	OM	329	4.3	7	0.1	137	1.6	3.1	0.4	2.2	0.6	0.43	0.73	0.78	0.10	0.79
10	OM	466	4.1	17	0.6	181	3.0	6.0	0.8	3.4	0.7	0.40	0.76	0.78	0.12	0.67
11	OM	167	5.8	13	0.6	88	2.7	4.9	0.6	2.2	0.5	0.25	0.77	0.76	0.12	0.95
12	OM	188	6.2	12	0.5	94	2.5	4.6	0.5	2.1	0.6	0.28	0.80	0.81	0.12	0.99
13	SH	267	24.2	135	7.0	457	20.7	45.2	5.7	22.7	4.6	1.33	5.15	4.88	0.70	4.20
14	SH	270	25.1	78	5.2	635	23.0	49.2	6.2	25.0	5.2	1.62	5.02	5.18	0.79	4.71
15	SH	300	39.2	234	11.5	860	35.6	77.0	9.4	37.2	7.7	2.09	7.86	7.50	1.18	7.32
16	SH	302	35.9	193	10.1	636	29.6	67.8	8.4	34.3	7.5	2.01	7.85	7.90	1.12	6.93
17	SH	234	3.1	15	0.6	111	2.8	5.7	0.7	2.9	0.7	0.43	0.62	0.61	0.10	0.54
18	SH	265	26.4	115	6.1	392	17.6	40.4	5.3	22.0	5.1	1.60	5.45	5.32	0.85	5.14
19	SH	389	25.1	172	9.7	533	25.6	56.9	7.1	28.6	6.0	1.92	5.99	5.72	0.82	4.92
20	SH	332	22.3	139	5.9	364	16.8	38.0	4.8	20.4	4.7	1.54	4.93	4.55	0.70	4.05
21	SH	343	9.7	49	2.0	233	6.9	15.3	1.9	8.1	1.9	0.77	2.04	1.77	0.28	1.84
22	SH	412	14.9	106	5.2	456	16.9	37.0	4.6	18.8	3.7	1.42	3.46	3.58	0.49	2.97
23	SH	442	12.2	110	4.8	394	13.8	29.9	3.7	14.5	3.0	1.30	2.75	2.72	0.41	2.37
Ossok mean		516	9.9	46	2.9	333	12.4	25.8	3.1	12.4	2.4	0.82	2.26	2.17	0.29	1.80
std. dev.		302	6.5	46	2.6	248	10.9	23.2	2.8	11.2	2.0	0.47	1.66	1.59	0.20	1.27
Shabogamo mean		323	21.6	122	6.2	461	19.0	42.0	5.2	21.3	4.5	1.46	4.65	4.52	0.68	4.09
std. dev.		64	10.4	60	3.2	195	9.0	20.0	2.5	9.8	2.1	0.48	2.16	2.13	0.32	1.97
SH *		317	33	153	8	428	15.4	35.7	4.5	21.0	4.6	1.6	5.0			4.6
std. dev.		55	18	96	6	223	2.0	4.6	0.6	2.9	0.6	0.2	0.6			0.6
MG *		343	32	157	10	466	21.2	47.4	5.8	26.1	5.3	1.8	5.5			4.8
std. dev.		85	14	68	3	433	7.8	17.6	2.2	9.7	2.1	0.5	2.1			1.9

Analysis of Ga, V, Sc, Li, Be, Cu, Pb, Zn, Ni, Rb, Cr, Mo and Co by the Newfoundland Department of Mines and Energy chemical laboratory.

MRG-1 standard
SY-2 standard

Analysis of MRG-1 and SY-2 by the Newfoundland Department of Mines and Energy chemical laboratory.

The values of SH * and MG * are plots of average Shabogamo Gabbro and Michael Gabbro chemical data taken from Gower *et al.* (1991a).

The major-element data, and Ga, V, Sc, Li, Be, Rb and metal contents were collected by ICP-MS methods at the geochemical laboratory of the Newfoundland Department of Mines and Energy in St. John's. These data were determined in the Spring of 1991.

Trace- and Rare-Earth-Element Data

The trace- and rare-earth-element data were collected by ICP-MS methods at the Department of Earth Sciences, Memorial University of Newfoundland, under the supervision of Dr. Simon E. Jackson. The data were obtained in November 1991. The following notes on the data and the procedure are reproduced from Dr. Jackson's introductory remarks, which accompanied the analytical results.

Table A2-3. Continued

Ho	Er	Tm	Yb	Lu	Hf	Ta	Th	Ga	V	Sc	Li	Be	Cu	Pb	Zn	Ni	Rb	Cr	Mo	Co
0.54	1.40	0.23	1.59	0.21	2.94	0.35	3.68						39	7	88	17	50	100	4	25
1.01	2.93	0.40	2.79	0.42	4.31	0.32	2.32	30	255	40.1	23.2	1.3	56	116	5	69	30	208	4	36
0.13	0.43	0.05	0.45	0.08	0.38	0.01	0.06						98	-1	66	157	10	325	3	39
0.48	1.37	0.18	1.20	0.19	0.81	0.14	0.37	30	139	27.3	19.1	1.7	15	118	6	78	10	237	4	29
0.24	0.81	0.13	1.01	0.16	1.46	0.09	0.09						14	3	91	166	10	108	4	37
0.39	1.02	0.15	0.91	0.13	1.74	0.21	0.24						39	3	128	46	10	91	3	27
0.31	0.93	0.12	0.88	0.15	0.73	0.04	0.05						115	1	127	121	5	134	4	42
0.50	1.38	0.19	1.23	0.21	1.48	0.22	0.30	30	260	31.7	14.7	1.4	39	128	8	68	15	220	4	32
0.16	0.46	0.06	0.49	0.07	0.27	0.01	0.01						52	-1	63	243	10	285	4	43
0.14	0.46	0.07	0.37	0.06	0.48	0.03	0.10						54	-1	66	325	10	155	4	49
0.21	0.66	0.09	0.69	0.12	0.43	0.04	0.23	19	134	29.1	1.6	0.2	94	54	-1	318	15	514	3	42
0.22	0.67	0.10	0.65	0.11	0.32	0.02	0.17						96	-1	61	699	10	45	3	61
0.90	2.52	0.35	2.23	0.39	3.52	0.30	1.29						73	5	108	132	20	129	3	41
0.97	2.95	0.42	2.77	0.36	2.35	0.29	2.73	28	215	31.2	23.2	1.1	82	132	6	158	25	77	4	49
1.49	4.34	0.63	4.05	0.64	5.94	0.57	1.98	30	224	39.2	21.7	1.8	43	119	9	38	55	37	3	34
1.38	3.88	0.60	3.70	0.58	4.62	0.49	3.25	33	277	40.3	19.0	1.7	63	139	6	69	40	183	4	38
0.12	0.30	0.05	0.34	0.05	0.39	0.03	0.24	19	34	6.1	2.5	0.9	20	58	-1	328	10	225	4	46
1.04	2.97	0.42	2.55	0.44	3.23	0.31	2.15	32	302	48.0	10.6	1.0	48	124	1	56	20	191	4	38
0.95	2.76	0.38	2.21	0.40	4.36	0.50	2.37	36	236	22.3	6.9	1.4	31	151	2	69	15	172	5	44
0.85	2.42	0.31	2.35	0.34	3.54	0.32	1.53	31	195	29.6	6.1	1.6	35	119	-1	89	15	84	4	42
0.36	0.95	0.14	0.79	0.14	1.24	0.10	0.49						36	-1	69	152	10	44	4	39
0.59	1.67	0.22	1.42	0.24	2.66	0.26	1.51	18	67	10.2	9.2	0.6	21	67	-1	130	20	89	3	34
0.47	1.40	0.17	1.30	0.17	2.48	0.23	1.10	28	80	11.4	5.8	0.7								
0.36	1.04	0.15	1.02	0.16	1.28	0.12	0.64	27	197	32.1	14.7	1.2	59	36	59	192	15	202	4	39
0.24	0.66	0.09	0.63	0.09	1.19	0.12	1.10	5	61	4.9	8.1	0.6	32	51	44	182	12	124	0	10
0.83	2.38	0.34	2.16	0.34	3.12	0.31	1.69	28	181	26.5	11.7	1.2	45	91	20	122	23	123	4	41
0.40	1.16	0.18	1.09	0.17	1.48	0.16	0.87	6	91	14.0	7.2	0.4	20	53	36	79	13	63	1	5
1.6	2.7		2.4	0.4			3.0	21.0	166.0				38	9	117	127	25	93		
2.6	0.3		0.3	0.0			3.0	2.9	61.0				17	6	60	104	24	62		
1.0	2.8		2.5	0.4			4.0	21.0	203.0		10		44	1	125	107	25	142	4	
0.4	1.1		1.0	0.2			3.0	6.0	74.0		4		50	1	29	80	13	175	1	
												10	115	219	-1	160	-5	328	10	5
								29	51	8	96	22	3	86	257	5	195	10	3	7

All results are in ppm. Note that in addition to the quantitative determinations of the REE, Y and Th, data are given for Sr, Nb, Ta, Zr, Ba, and Hf. The latter elements are generally collected quantitatively by the digestion procedure but on occasion may not be. They should therefore be treated as semi-quantitative only (development work is in progress to improve the reliability of these analyses). Extended chondrite-normalized plots have been prepared for each sample using the chondrite abundances (CHONDRITE) of Taylor and McLennan (1985), compiled from Anders and Ebihara (1982), except for the REE data, which is from Evensen *et al.* (1978).

The analytical procedure was as follows: (1) sintering of a 0.2 g sample aliquot with sodium peroxide, (2) dissolution of the sinter cake, separation and dissolution of REE hydroxide-bearing precipitate, (3) analysis by ICP-MS using the method of internal standardization to correct for matrix and drift effects. The advantage of the sintering technique is that it ensures complete digestion of resistant REE-bearing accessory phases (e.g., zircon, fluorite) which may not dissolve during an acid digestion. Full details of the procedure are given in Longerich *et al.* (1990).

A pure quartz reagent blank (BLANK) and one or more certified geological reference standards (usually SY-2 (CANMET), W-2, BIR-1 (USGS)) were prepared and analyzed (acid digestion) performed in our (Department of Earth Sciences, Memorial University of Newfoundland) laboratory (SY-2 mun std add, W-1 Jenner, BIR-1 Jenner, reported by Jenner *et al.* (1990), are given in Table A2-4. Reagent blank concentrations are generally insignificant and have not been subtracted from sample concentrations.

Table A2-4 Analyses of standards, duplicate samples and blank

Name	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm
CHONDRITE	11.9	2.25	5.54	0.375	3.41	0.376	0.957	0.137	0.711	0.231
sy-2 mun std add	265	119	268	31	447	69	162	19.6	76	15.8
BIR-1(Jenner)	109	16.8	16	0.508	7.64	0.594	1.8	0.341	2.19	1.07
W-1(Jenner)	193	22.6	99	7.9	162	10.9	24.0	3.27	14.4	3.65
Limit of Detection	0.008	0.004	0.020	0.010	0.005	0.006	0.003	0.004	0.003	0.005
BIR-1 (analyzed)	124	13.3	14	0.6	10	0.8	2.0	0.4	2.2	1.0
W-2 (analyzed)	219	18.3	91	8.5	173	10.5	23.3	2.9	12.8	3.1
BLANK	15	0.3	1	0.0	1	0.1	0.1	0.0	0.0	0.0
sample 4	766	12.6	22	5.8	312	27.1	52.6	5.9	23.1	4.1
sample 4*	712	12.9	20	5.9	345	28.2	55.5	6.2	23.3	4.3
sample 7	518	8.2	19	0.9	393	3.9	8.0	1.1	5.0	1.4
sample 7*	530	8.5	22	1.0	327	4.0	8.6	1.2	5.4	1.3

Sample 4 and 4* are duplicate analyses.
Sample 7 and 7* are duplicate analyses.

Several inter-element interferences are present in ICP-MS analysis. The instrument is optimized such that for most rock types the interferences are at a sufficiently low level that they can be adequately corrected. However, due to a small Ba molecular ion interference on Eu, a problem can occur in samples with extremely high Ba/Eu. At very high Ba/Eu ratios (Ba(ppm)/Eu(ppm) > 1000, chondrite-normalized Ba/Eu > 25), the correction becomes larger than the Eu signal and any error in the correction starts to be significant.

MAPS NOT FILMED

CARTES NON REPRODUITES